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7 Abstract

This report provides Hanford site-wide geology and hydrology information to be used in Westinghouse Hanford Company documents and reports. The principal objective of this study was to outline the geology and hydrogeology of the Hanford Site in south-central Washington state. The Hanford Site is situated in the Pasco Basin, which is part of the Yakima Fold Belt. The Hanford Site is underlain by the flood basalts of the Columbia River Basalt Group. These basalts are overlain by the fluvial-lacustrine sediments of the Miocene-Pliocene Ringold Formation and the cataclysmic flood deposits of the Hanford formation. Several laterally restricted units are found between the Hanford formation and Ringold Formation. The hydrogeology of the Hanford Site is characterized by a multiaquifer system that consists of four hydrogeologic units. These units correspond to the upper three formations of the Miocene-aged Columbia River Basalt Group and the Miocene to Pliocene-aged Ringold Formation and Pleistocene-aged Hanford formation. Aquifers present in the basalts are confined and are generally found in sedimentary interbeds and/or interflow zones that occur between dense basalt flows. The uppermost aquifer system is regionally unconfined and consists of fluvial, lacustrine, and glaciofluvial sediments of the Ringold Formation and the Hanford formation.

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1.0 SITE BACKGROUND AND PHYSICAL SETTING

1.1 INTRODUCTION

The physical setting of the Hanford Site has been extensively characterized as a result of past activities. These activities include the siting of nuclear reactors, characterization activities for the Basalt Waste Isolation Project, and waste management activities. The purpose of this report is to summarize the physical and environmental setting of the Hanford Site. Topics discussed include topography, physiography, geology (stratigraphy, tectonic framework, seismicity), and hydrology. A more detailed discussion of the Hanford Site and the regional setting is given in DOE (1987, 1988), Myers and Price (1979), Meyers et al. (1981), and Reidel and Hooper (1989a).

1.2 TOPOGRAPHY AND PHYSIOGRAPHY

The Hanford Site (Figure 1-1) is situated within the Pasco Basin of south-central Washington. The Pasco Basin is one of a number of topographic depressions located within the Columbia Plateau Physiographic Province (Figure 1-2), a broad basin located between the Cascade Range and the Rocky Mountains. The Columbia Intermontane Province is the product of Miocene continental flood basalt volcanism and regional deformation that occurred over the past 17 million years. The Pasco Basin is bounded on the north by the Saddle Mountains; on the west by Umtanum Ridge, Yakima Ridge, and the Rattlesnake Hills; on the south by Rattlesnake Mountain and the Rattlesnake Hills; and on the east by the Palouse slope (Figure 1-1).

The physiography of the Hanford Site is dominated by the low-relief plains of the Central Plains physiographic region and anticlinal ridges of the Yakima Folds physiographic region (Figure 1-3). Surface topography seen at the Hanford Site is the result of (1) uplift of anticlinal ridges, (2) Pleistocene cataclysmic flooding, (3) Holocene eolian activity, and (4) landsliding. Uplift of the ridges began in the Miocene epoch and continues to the present. Cataclysmic flooding occurred when ice dams in western Montana and northern Idaho were breached, allowing large volumes of water to spill across eastern and central Washington. The last major flood occurred about 13,000 years ago, during the late Pleistocene Epoch. Anastomosing flood channels, giant current ripples, bergmounds, and giant flood bars are among the landforms created by the floods. Since the end of the Pleistocene Epoch, winds have locally reworked the flood sediments, depositing dune sands in the lower elevations and loess (windblown silt) around the margins of the Pasco Basin. Generally, sand dunes have been stabilized by anchoring vegetation except where they have been reactivated where vegetation is disturbed (Figure 1-4).

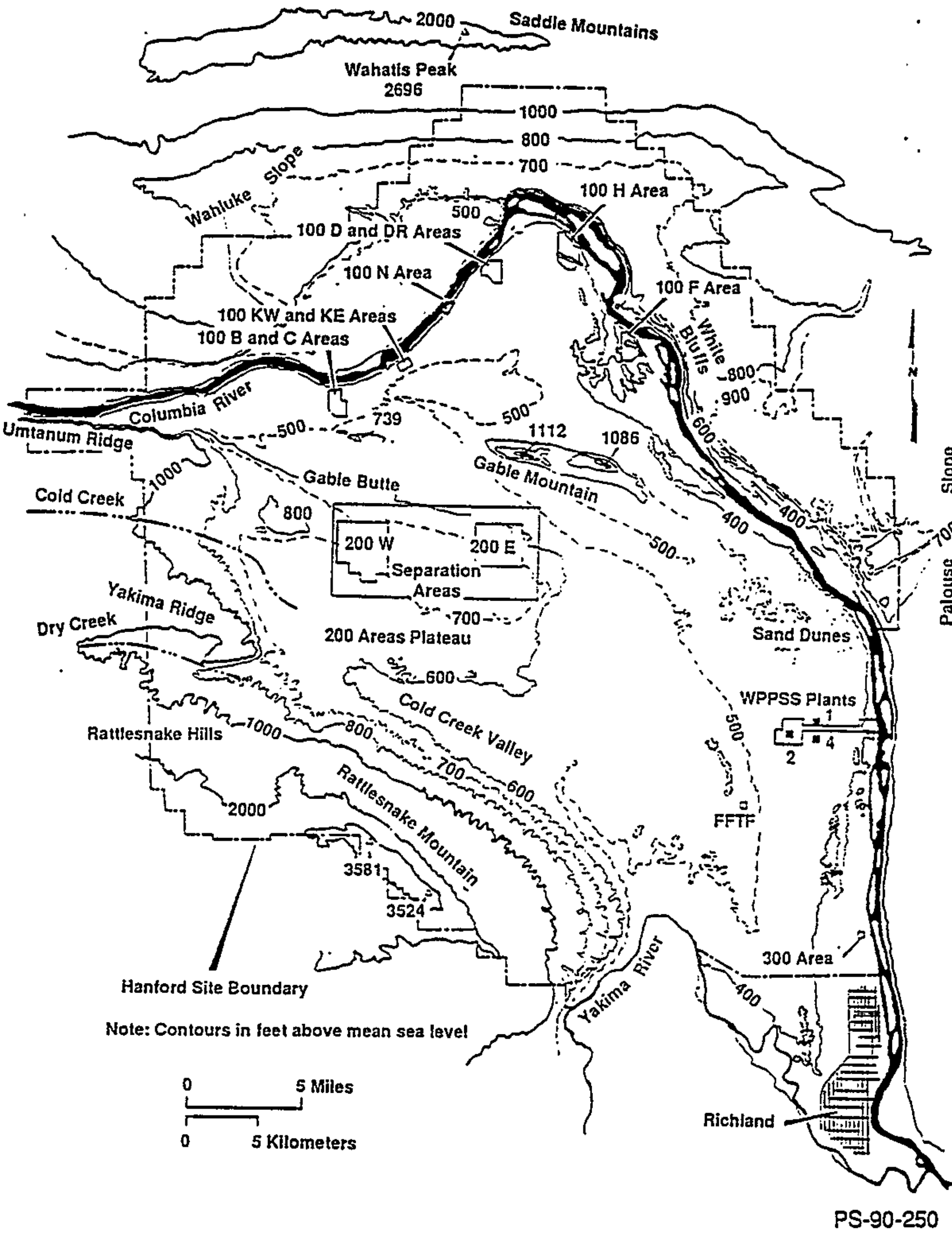

Figure 1-1. Topography and Location Map for the Hanford Site.

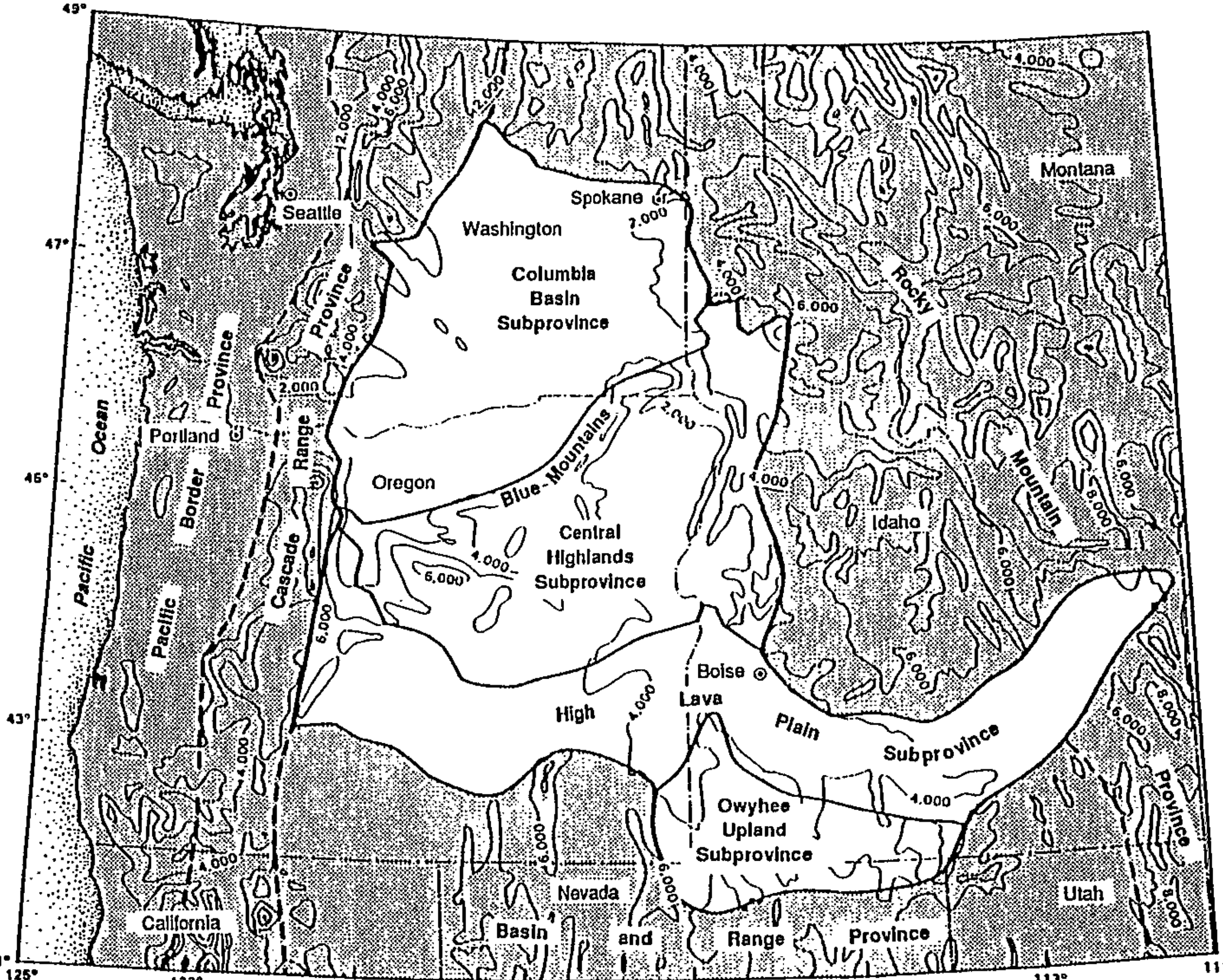

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Figure 1-2. Divisions of the Columbia Intermontane Province and Adjacent Snake River Plains Province.

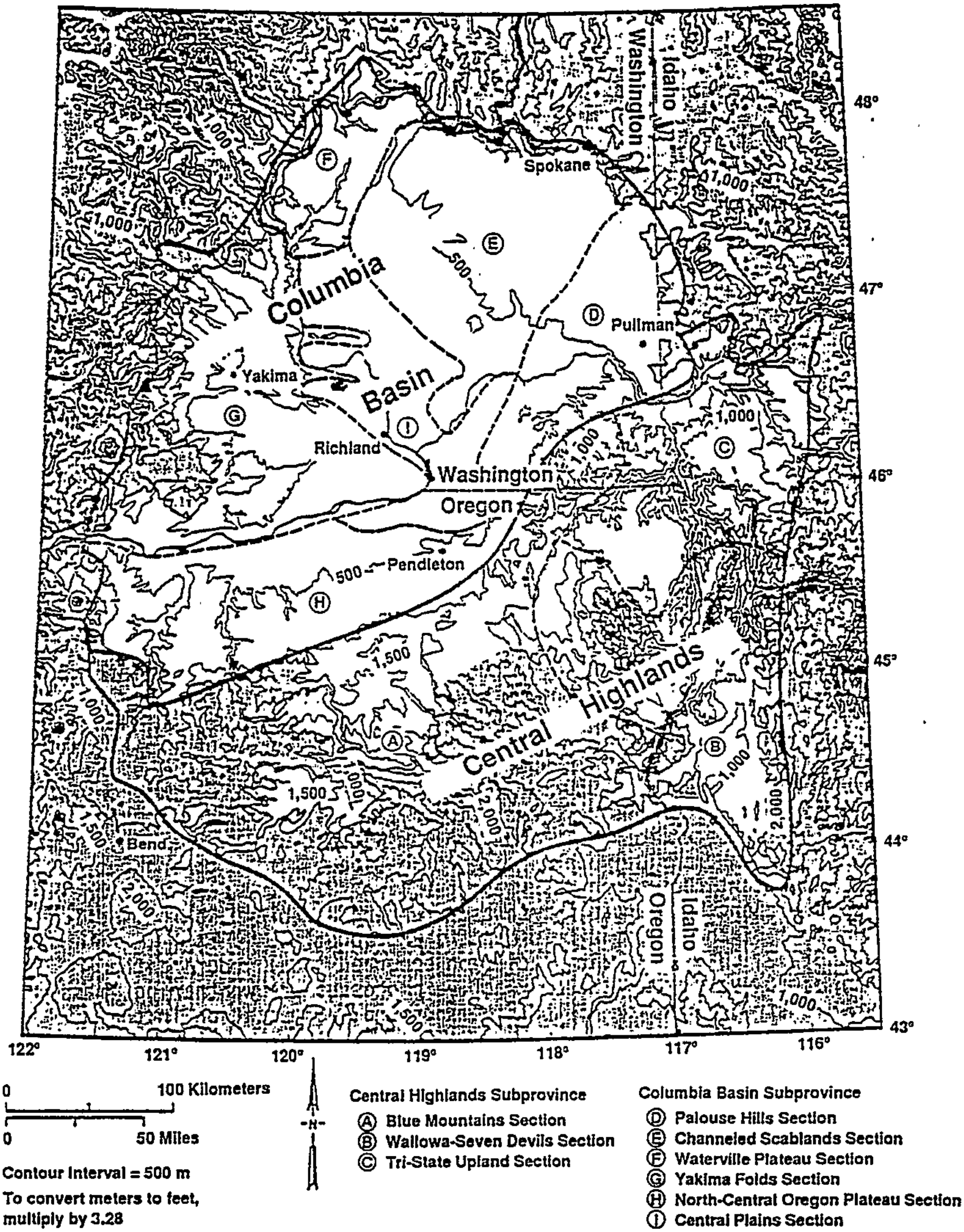

Figure 1-3. Geomorphic Units Within the Central Highlands and Columbia Basin Subprovinces that Contain the Columbia River Basalt Group.

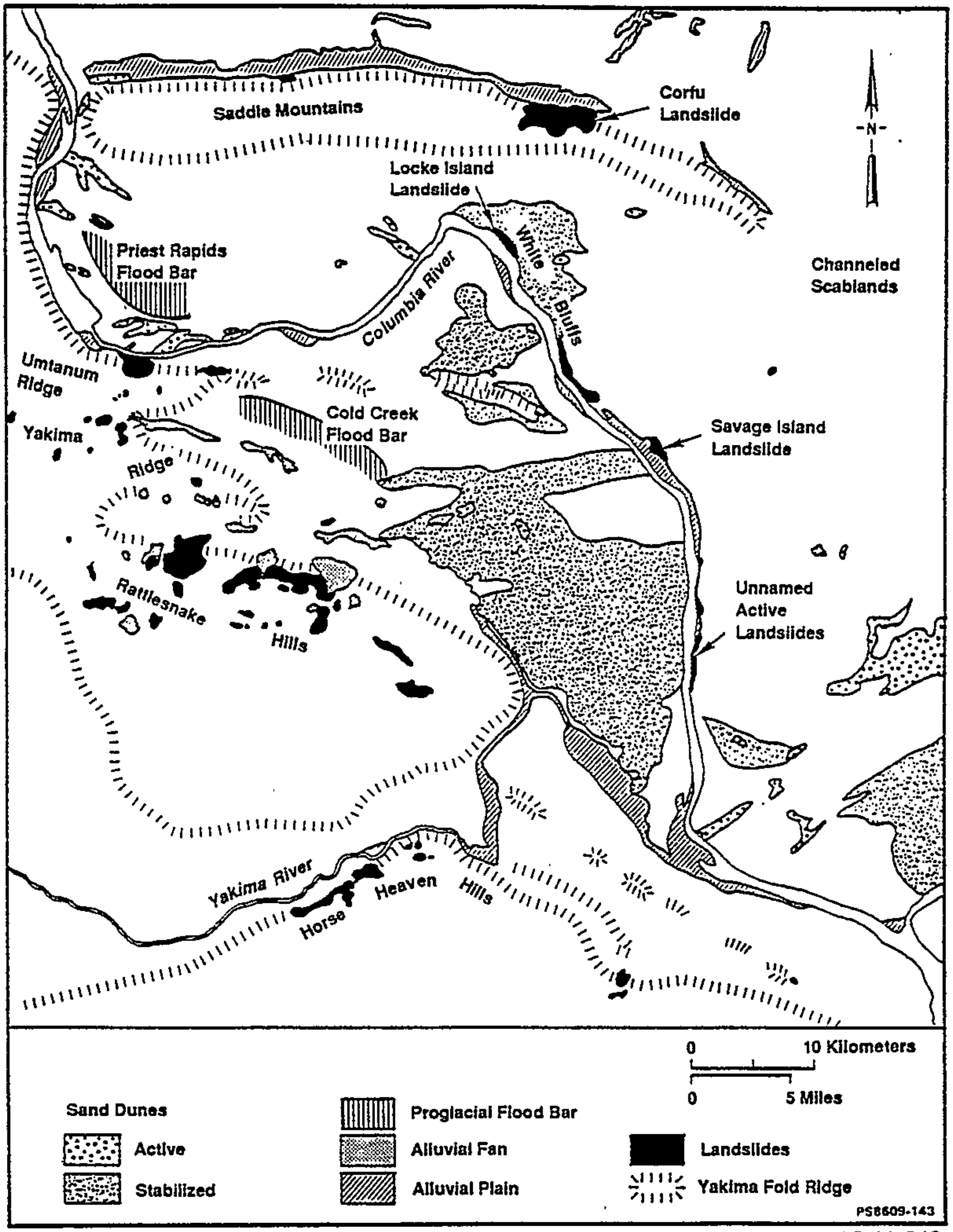

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Figure 1-4. Landforms of the Pasco Basin and the Hanford Site.

A series of numbered areas has been delineated at the Hanford Site. The 100 Areas are situated in the northern part of the Hanford Site adjacent to the Columbia River in an area commonly called the "Horn." The elevation of the Horn is between 390 ft (119 m) and 470 ft (143 m) with a slight increase in elevation away from the Columbia River. The 200 Areas are situated on a broad flat area called the 200 Areas plateau. The 200 Areas plateau is near the center of the Hanford Site at an elevation of approximately 650 ft (198 m) to 750 ft (229 m) above mean sea level (msl). The plateau decreases in elevation to the north, northwest, and east toward the Columbia River, and plateau escarpments have elevation changes of between 50 ft (15 m) to 100 ft (30 m). The 300 and 1100 areas are situated adjacent to or near the Columbia River in the southeastern corner of the Hanford Site at an elevation of about 370 ft (113 m) to 400 ft (122 m).

2.0 GEOLOGY

The Hanford Site lies in the Pasco Basin near the eastern limit of the Yakima Fold Belt. The Pasco Basin is a structural depression bounded by anticlinal ridges on the north, west, and south and a monocline on the east (Figure 2-1). The Pasco Basin is divided by the Gable Mountain anticline into the Wahluke syncline to the north and the Cold Creek syncline to the south (Figure 2-1). The Hanford Site is underlain by Miocene-aged basalt of the Columbia River Basalt Group and late Miocene to Pleistocene suprabasalt sediments (Figure 2-2). The basalts and sediments thicken into the Pasco Basin and generally reach maximum thicknesses in the Cold Creek syncline. Older Cenozoic sedimentary and volcaniclastic rocks underlying the basalts are not exposed at the surface near the Hanford Site. Hanford Site stratigraphy is summarized in Figure 2-2 and described below.

2.1 COLUMBIA RIVER BASALT GROUP

The Columbia River Basalt Group (Figure 2-2) comprises an assemblage of tholeiitic, continental flood basalts of Miocene age. These flows cover an area of more than 63,000 mi^2 (163,157 km^2) in Washington, Oregon, and Idaho and have an estimated volume of about 40,800 mi^3 (174,356 km^3) (Tolan et al. 1989). Isotopic age determinations indicate that basalt flows were erupted approximately 17 to 6 Ma (million years before present), with more than 98% by volume being erupted in a 2.5-million year period (17 to 14.5 Ma) (Reidel et al. 1989b). The most current information on the Columbia River Basalt Group is presented in Reidel and Hooper (1989a).

Columbia River basalt flows were erupted from north-northwest-trending fissures or linear vent systems in north-central and northeastern Oregon, eastern Washington, and western Idaho (Swanson et al. 1979). The Columbia River Basalt Group is formally divided into five formations (from oldest to youngest): Imnaha Basalt, Picture Gorge Basalt, Grande Ronde Basalt, Wanapum Basalt, and Saddle Mountains Basalt. Of these, only the Picture Gorge Basalt is not known to be present in the Pasco Basin. The Saddle Mountains Basalt, divided into the Ice Harbor, Elephant Mountain, Pomona, Esquatzel, Asotin, Wilbur Creek, and Umatilla members (Figure 2-2), forms the uppermost basalt unit throughout most of the Pasco Basin. The Elephant Mountain Member is the uppermost unit beneath most of the Hanford Site except near the 300 Area where the Ice Harbor Member is found and north of the 200 Areas where the Saddle Mountains Basalt has been eroded down to the Umatilla Member locally. The Elephant Mountain Member also has been eroded in the vicinity of the northeast corner of 200 East Area. On anticlinal ridges bounding the Pasco Basin, erosion has removed the Saddle Mountains Basalt, exposing the Wanapum and Grande Ronde basalts.

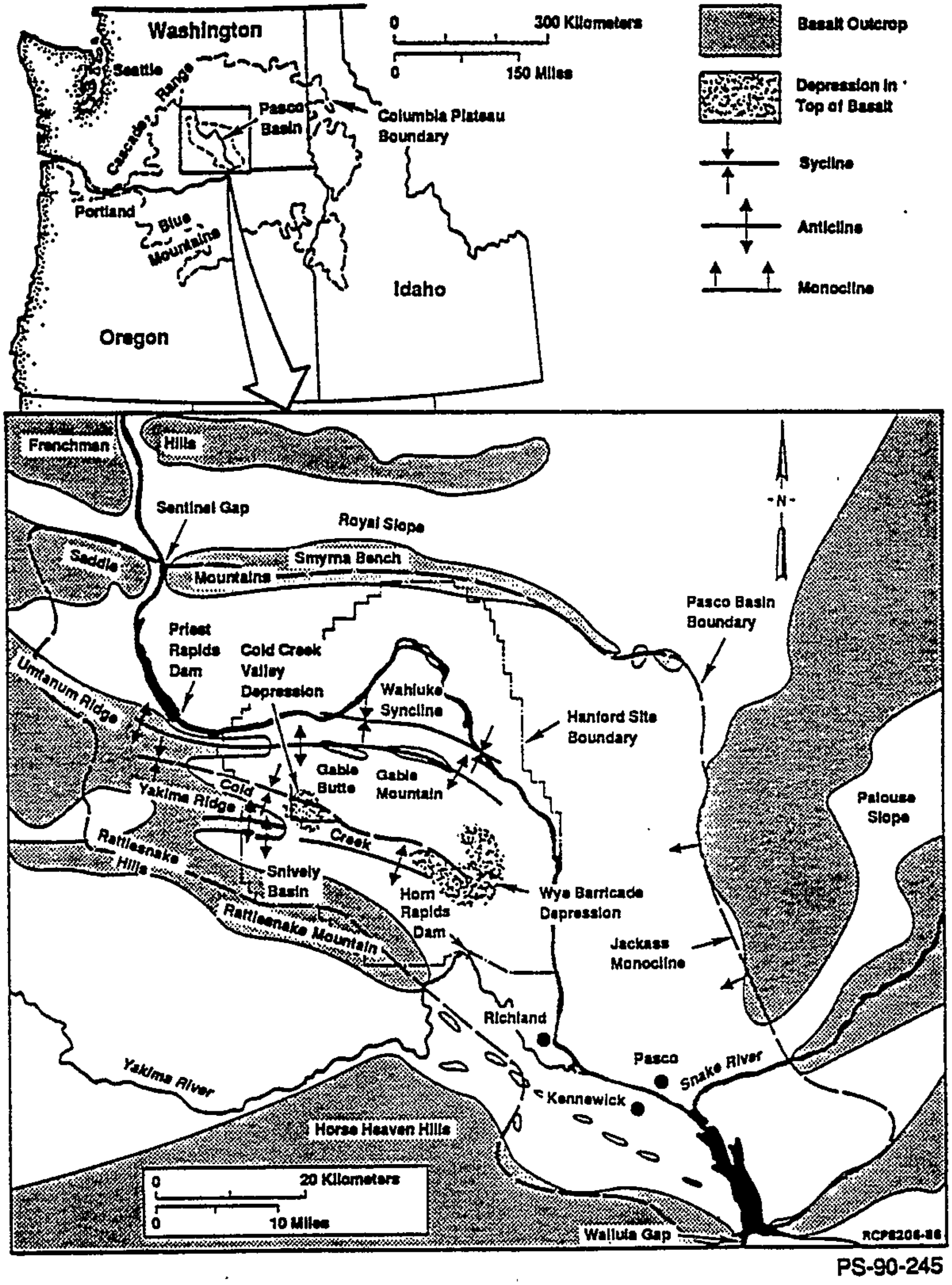

Figure 2-1. Geologic Structures of the Pasco Basin and the Hanford Site.

Period	Epoch	Group	Formation	Isotopic Age Dates Years x 10^6	Member (Formal and Informal)	Sediment Stratigraphy or Basalt Flows	
QUATERNARY	Holocene				Surficial Units	Loess, Sand Dunes, Alluvium and Alluvial Fans, Land Slides, Talus, Colluvium	
QUATERNARY	Pleisto-cene		Han-ford		Touchet beds / Pasco gravels		
QUATERNARY	Pleisto-cene					Plio-Pleistocene unit	
TERTIARY	Plio-cene		Ringold				
TERTIARY	Miocene	Columbia River Basalt Group	Saddle Mountains Basalt	8.5	Ice Harbor Member	basalt of Goose Island	
						basalt of Martindale	
						basalt of Basin City	
						Levey interbed	Ellensburg Formation
				10.5	Elephant Mountain Member	basalt of Ward Gap	
						basalt of Elephant Mountain	
						Rattlesnake Ridge interbed	Ellensburg Formation
				12.0	Pomona Member	basalt of Pomona	
						Selah interbed	Ellensburg Formation
					Esquatzel Member	basalt of Gable Mountain	
						Cold Creek interbed	Ellensburg Formation
				13.5	Asotin Member	basalt of Huntzinger	
					Wilbur Creek Member	basalt of Lapwai	
						basalt of Wahluke	
					Umatilla Member	basalt of Sillusi	
						basalt of Umatilla	
				14.5		Mabton interbed	Ellensburg Formation
			Wanapum Basalt		Priest Rapids Member	basalt of Lolo	
						basalt of Rosalia	
						Quincy interbed	Ellensburg Formation
					Roza Member	basalt of Roza	
						Squaw Creek interbed	Ellensburg Formation
					Frenchman Springs Member	basalt of Lyons Ferry	
						basalt of Sentinel Gap	
						basalt of Sand Hollow	
						basalt of Silver Falls	
						basalt of Ginkgo	
						basalt of Palouse Falls	
				15.6		Vantage interbed	Ellensburg Formation
			Grande Ronde Basalt*		N_2 Sentinel Bluffs Unit	basalt of Museum	
						basalt of Rocky Coulee	
						basalt of Levering	
						basalt of Cohassett	
						basalt of Birkett	
						basalt of McCoy Canyon	
				16.5	N_2 Umtanum Unit	basalt of Umtanum	
					N_2 Slack Canyon Unit		
					N_2 Ortley Unit	basalt of Benson Ranch	
					R_2 Grouse Creek Unit		
					R_2 Wapshilla Ridge Unit		
					R_2 Mt. Horrible Unit		
					N_1 China Creek Unit		
					R_1 Teepee Butte Unit		
					R_1 Buckhorn Springs Unit		
			Imnaha	17.5	Rock Creek Unit		
					American Bar Unit		

*The Grande Ronde Basalt consists of at least 120 major basalt flows. Only a few flows have been named. N_2, R_2, N_1 and R_1 are magnetostratigraphic units.

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Figure 2-2. Generalized Stratigraphy of the Hanford Site.

2.2 ELLENSBURG FORMATION

The Ellensburg Formation consists of all sedimentary units that occur between the basalt flows of the Columbia River Basalt Group in the central Columbia Basin. The Ellensburg Formation generally displays two main lithologies, volcaniclastics, and siliciclastics. The volcaniclastics consist mainly of primary pyroclastic air fall deposits and reworked epiclastics derived from volcanic terrains west of the Columbia Plateau. Siliciclastic strata in the Ellensburg Formation consist of clastic, plutonic, and metamorphic detritus derived from the Rocky Mountain terrain. These two lithologies occur as both distinct and mixed in the Pasco Basin. A detailed discussion of the Ellensburg Formation in the Hanford Site is given by Reidel and Fecht (1981). Smith et al. (1989) provides a discussion of age equivalent units adjacent to the Columbia Plateau.

The stratigraphic names for individual units of the Ellensburg Formation are given in Figure 2-2. The nomenclature for these units is based on the upper- and lower-bounding basalt flows and thus the names are valid only for those areas where the bounding basalt flows occur. Because the Pasco Basin is an area where most bounding flows occur, the names given in Figure 1-6 are applicable to the Hanford Site. At the Hanford Site the three uppermost units of the Ellensburg Formation are the Levey interbed, the Rattlesnake Ridge interbed, and the Selah interbed.

2.2.1 Levey Interbed

The Levey interbed is the uppermost unit of the Ellensburg Formation and occurs between the Ice Harbor Member and the Elephant Mountain Member. It is confined to the vicinity of the 300 Area. The Levey interbed is a tuffaceous sandstone along its northern edge and a fine-grained tuffaceous siltstone to sandstone along its western and southern margins.

2.2.2 Rattlesnake Ridge Interbed

The Rattlesnake Ridge interbed is bounded on the top by the Elephant Mountain Member and on the bottom by the Pomona Member. The interbed is up to 108 ft (33 m) thick and dominated by three facies at the Hanford Site: (1) a lower clay or tuffaceous sandstone, (2) a middle, micaceous-arkosic and/or tuffaceous sandstone, and (3) an upper, tuffaceous siltstone to sandstone. The unit is found beneath most of the Hanford Site.

2.2.3 Selah Interbed

The Selah interbed is bounded on the top by the Pomona Member and on the bottom by the Esquatzel Member. The interbed is a variable mixture of silty to sandy vitric tuff, arkosic sands, tuffaceous clays, and locally thin stringers of predominately basaltic gravels. The Selah interbed is found beneath most of the Hanford Site.

2.3 SUPRABASALT SEDIMENTS

The suprabasalt sedimentary sequence at the Hanford Site is up to approximately 750 ft (230 m) thick in the west-central Cold Creek syncline, while it pinches out against the Saddle Mountains anticline, Gable Mountain/Umtanum Ridge anticline, Yakima Ridge anticline, and Rattlesnake Hills anticline (Figures 2-2 and 2-3). The suprabasalt sediments are dominated by laterally extensive deposits assigned to the late Miocene to Pliocene-aged Ringold Formation and the Pleistocene-aged Hanford formation (Figures 2-2 and 2-3). Locally occurring strata assigned to the informally defined Plio-Pleistocene unit, early "Palouse" soil, and pre-Missoula gravels compose the remainder of the sequence (Figure 2-3).

2.3.1 Ringold Formation

Recent studies of the Ringold Formation in the Pasco Basin and Hanford Site indicate it contains significant, previously undocumented stratigraphic variation (Lindsey and Gaylord 1989; Lindsey 1991). The Ringold Formation at the Hanford Site is up to 600 ft (185 m) thick in the deepest part of the Cold Creek syncline south of the 200 West Area and 560 ft (170 m) thick in the western Wahluke syncline near the 100-B Area. The Ringold Formation pinches out against the Gable Mountain, Yakima Ridge, Saddle Mountains, and Rattlesnake Mountain anticlines. It is largely absent in the northern and northeastern parts of the 200 East Area and adjacent areas to the north in the vicinity of West Pond.

The Ringold Formation consists of semi-indurated clay, silt, pedified mud, fine- to coarse-grained sand, and granule to cobble gravel that usually are divided into the (1) gravel, sand, and paleosols of the basal unit; (2) clay and silt of the lower unit; (3) gravel of the middle unit; (4) mud and lesser sand of the upper unit; and (5) basaltic detritus of the fanglomerate unit (Newcomb 1958; Newcomb et al. 1972; Myers et al. 1979; Bjornstad 1984; DOE 1988). Ringold strata also have been divided on the basis of facies types (Tallman et al. 1981) and fining upwards sequences (PSPL 1982). All of these stratigraphic divisions are of limited use because they are too generalized to account for marked local stratigraphic variation or they were defined in detail for relatively small areas (Lindsey and Gaylord 1989). The Ringold Formation is assigned a late Miocene to Pliocene age (Fecht et al. 1987; DOE 1988).

2.3.1.1 Ringold Sediment Types. Accurate stratigraphic interpretations depend on a clear understanding of sedimentary geometry. Recent studies of the Ringold Formation (Lindsey and Gaylord 1989; Lindsey 1991) indicate that it is best described and divided on the basis of sediment facies associations and their distribution. Facies associations in the Ringold Formation (defined on the basis of lithology, petrology, stratification, and pedogenic alteration) include fluvial gravel, fluvial sand, overbank deposits, lacustrine deposits, and basaltic gravel. The facies associations are summarized as follows:

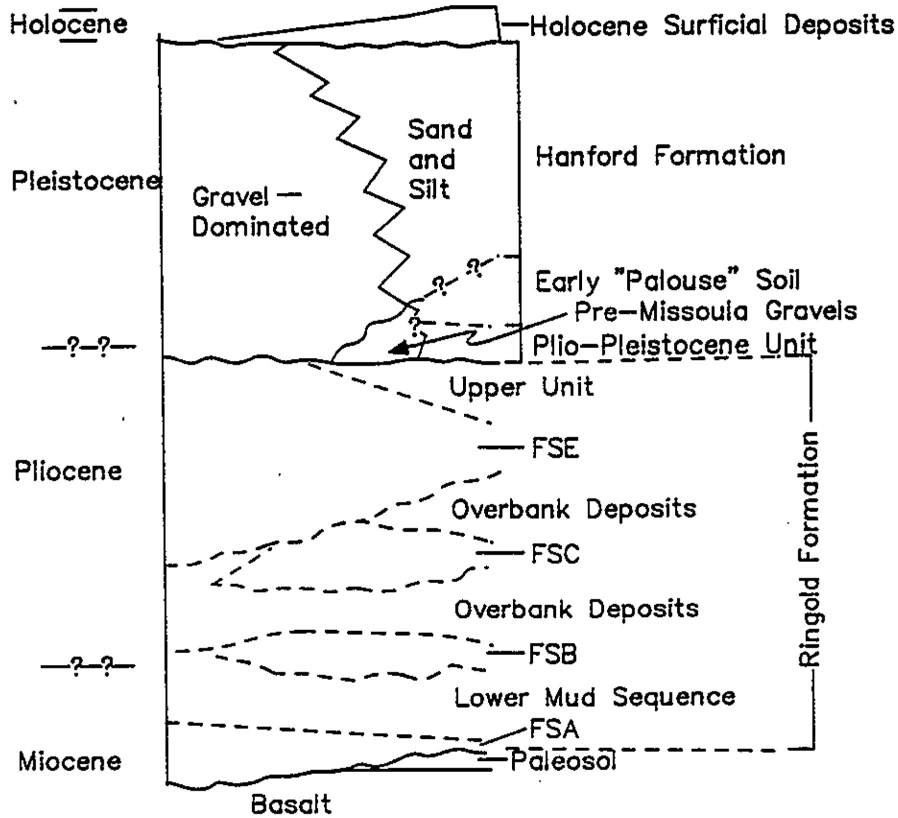

Figure 2-3. Generalized Stratigraphy of the Suprabasalt Sediments Beneath the Hanford Site.

1. Strata consisting dominantly of clast-supported granule to cobble gravel with a sandy matrix form the fluvial gravel facies association. Low angle to planar stratification, massive bedding, channels, and large-scale cross-bedding are found in outcrops. The association was deposited in a gravelly fluvial system characterized by wide, shallow, shifting channels.

2. Quartzo-feldspathic sands that display cross-bedding and cross-lamination in outcrop compose the fluvial sand facies association. These sands commonly form fining upwards sequences less than 1 m to several meters thick that were deposited in wide, shallow channels incised into a muddy floodplain.

3. The overbank facies association consists of laminated to massive silt, silty fine-grained sand, and paleosols containing variable amounts of $CaCO_3$. These sediments record deposition in a floodplain under proximal levee to more distal floodplain conditions.

4. Plane laminated to massive clay with thin silt and silty sand interbeds displaying some soft-sediment deformation characterize the lacustrine facies association. These sediments were deposited in a lake under standing water to deltaic conditions.

5. Massive to crudely stratified, weathered to unweathered basaltic detritus dominates the basaltic gravel facies association. This association was deposited largely by debris flows in alluvial fan settings.

2.3.1.2 Ringold Stratigraphy. The lower half of the Ringold Formation contains five separate stratigraphic intervals dominated by fluvial gravels. These gravels, designated units FSA, FSB, FSC, FSD1, and FSE (Figure 2-4), are separated by intervals containing deposits typical of the overbank and lacustrine facies associations. The uppermost gravel grades upward into interbedded fluvial sand and overbank deposits, which are in turn overlain by a second lacustrine interval (Figure 2-4).

Lowermost Ringold deposits consist of up to 150 ft (45 m) of fluvial gravel designated FSA (Figures 2-4 to 2-9). Unit FSA forms a tract that (1) enters the western Pasco Basin near Sentinel Gap, (2) extends southeast down the Wahluke syncline crossing the west end of the Gable Mountain structure, and (3) follows the Cold Creek syncline southeast to exit the basin near the east end of Rattlesnake Mountain. Unit FSA is not found in the vicinity of the 300 and 1100 areas and is absent from the Wahluke syncline near 100-D, 100-H, and 100-F areas (Figures 2-8 and 2-9). Fluvial sands dominate the lower 82 ft (25 m) of unit FSA in the western Cold Creek syncline west of 200 West Area (Figures 2-5 and 2-6). Strata assigned to the lower basal unit of the Ringold Formation in the western Cold Creek syncline and 200 West Area (DOE 1988) correlate to unit FSA.

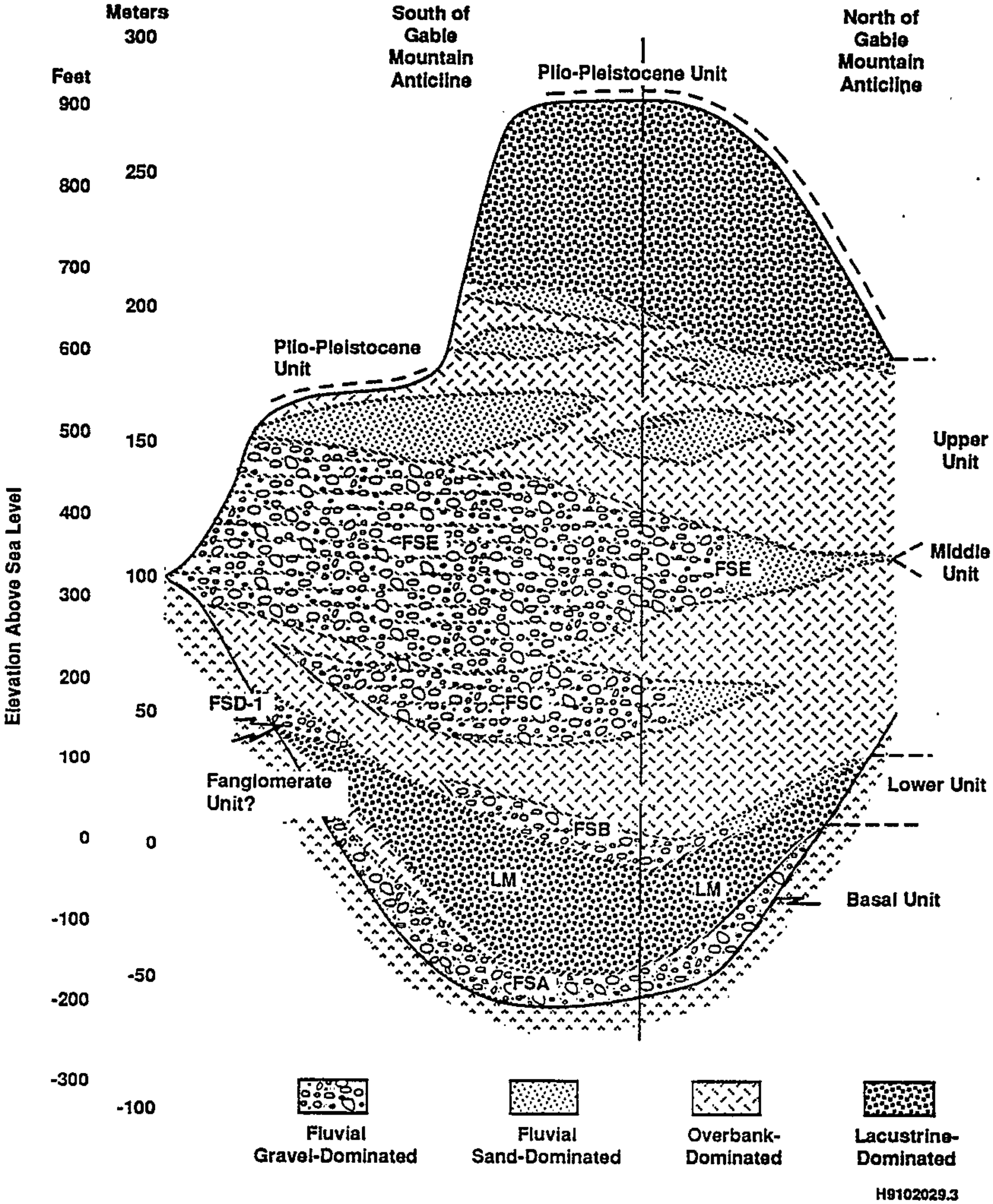

Figure 2-4. Generalized Stratigraphy of the Miocene-Pliocene Ringold Formation in the Pasco Basin. Figure Also Illustrates the Distribution of Major Sediment Facies in the Ringold Formation (Lindsey 1991).

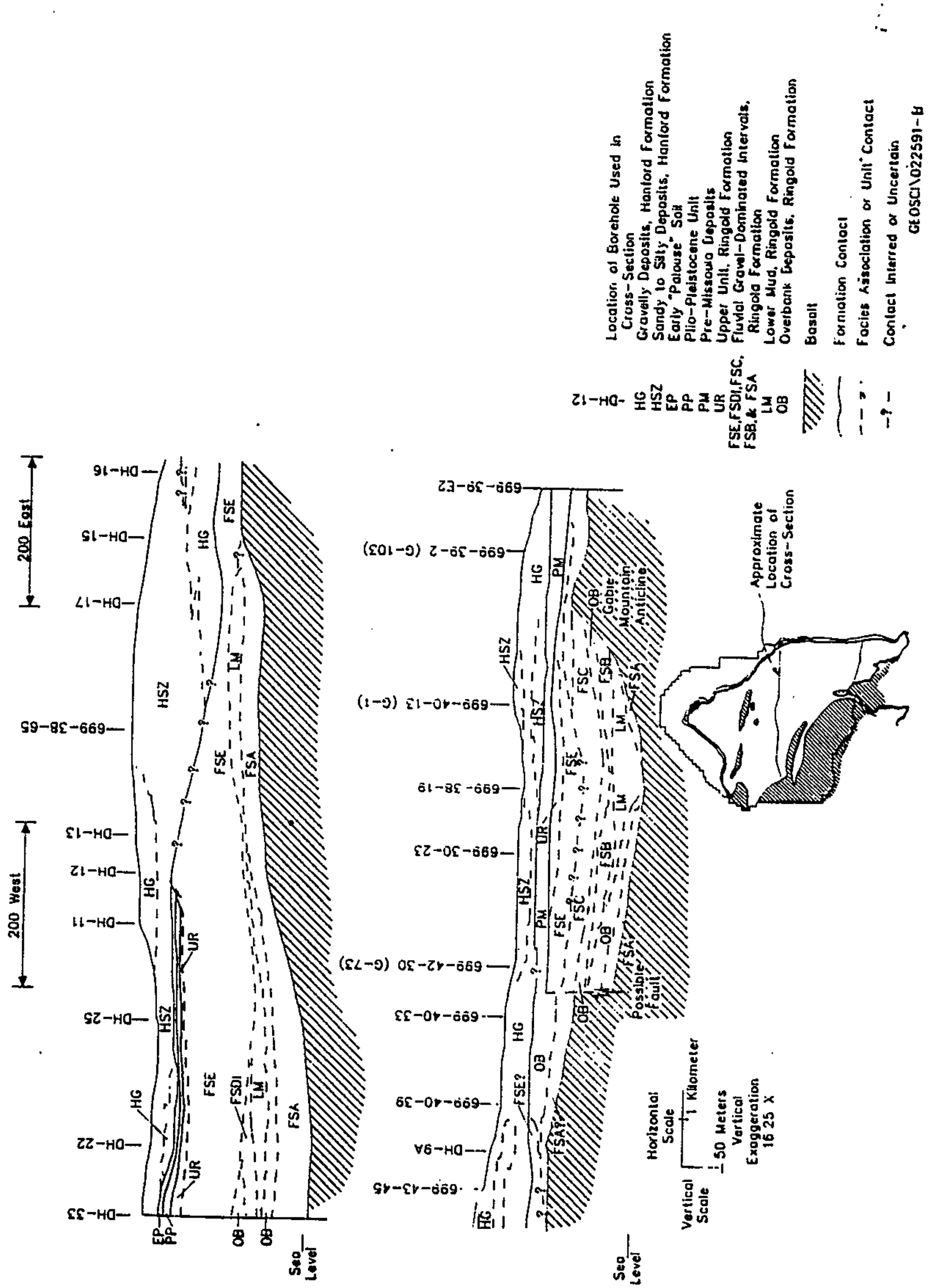

Figure 2-5. East-west Geologic Cross-section of the Suprabasalt Sediments at the Hanford Site. Cross-section Goes Through the 200 West and 200 East Areas.

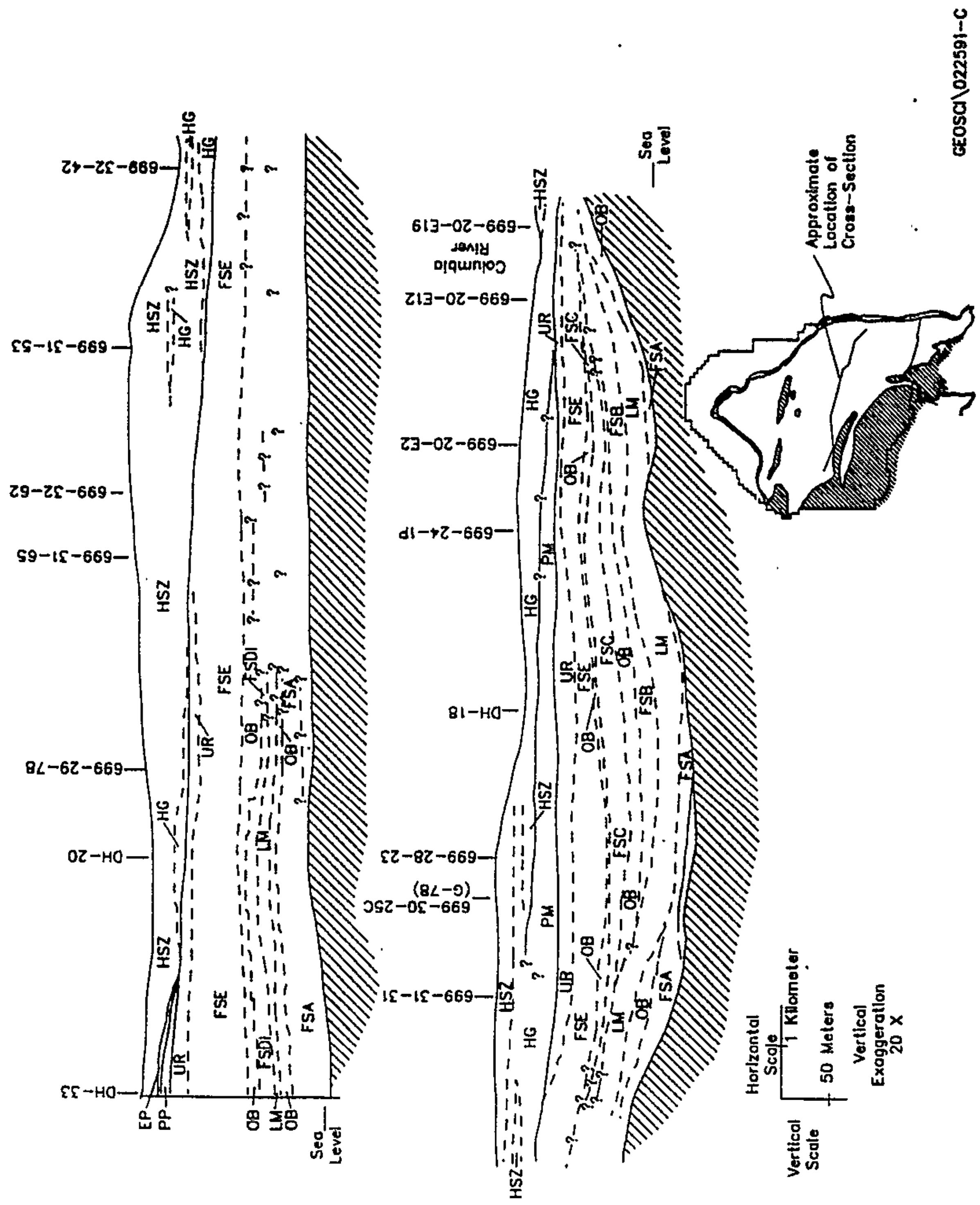

Figure 2-6. East-west Geologic Cross-section of the Suprabasalt Sediments Along the Axis of the Cold Creek Syncline South of 200 East and 200 West Areas. See Figure 2-5 for Explanation of Symbols and Abbreviations.

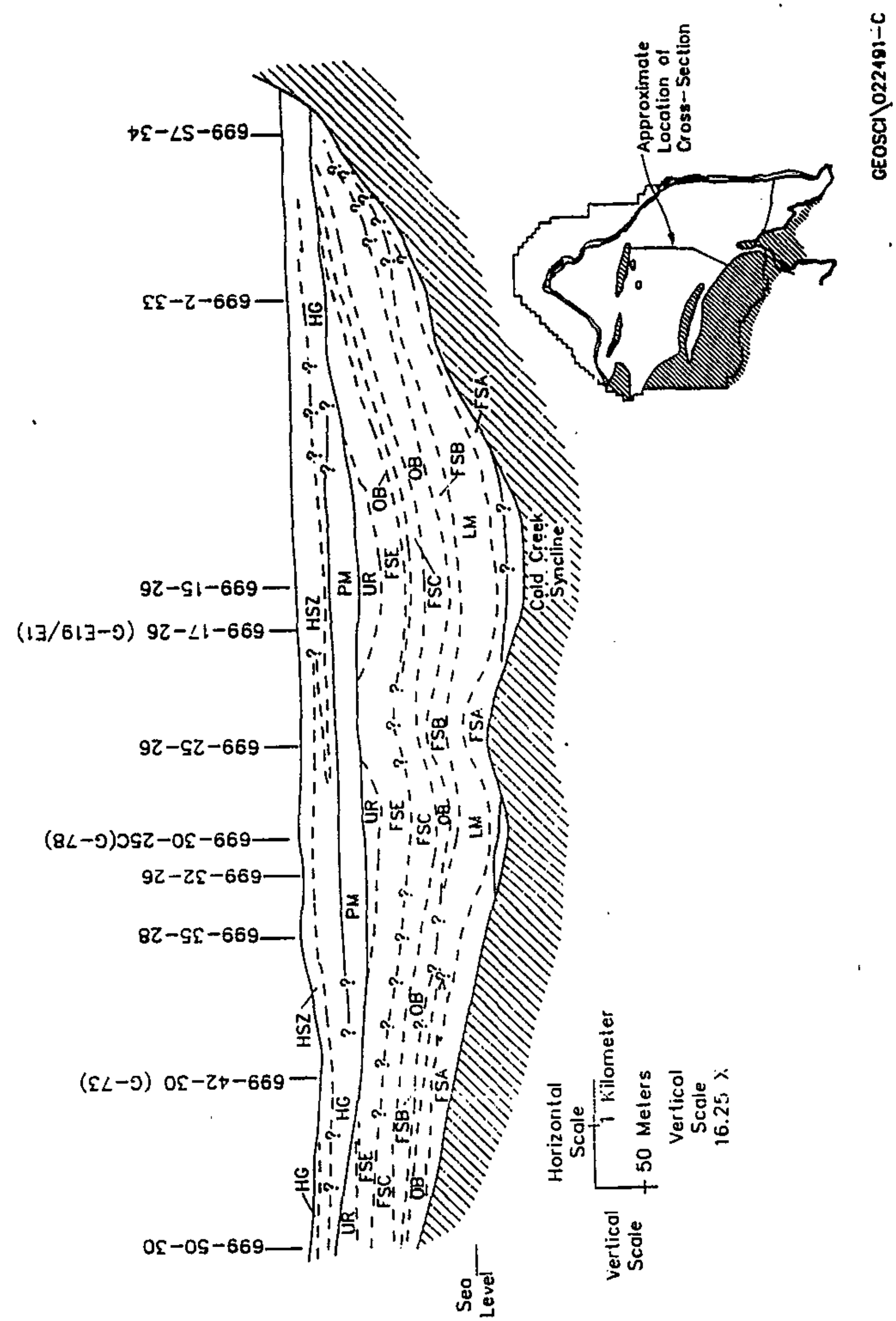

Figure 2-7. North-south Geologic Cross-section of the Suprabasalt Sediments Across the East-central Cold Creek Syncline East of the 200 East Area. See Figure 2-5 for Explanation of Symbols and Abbreviations.

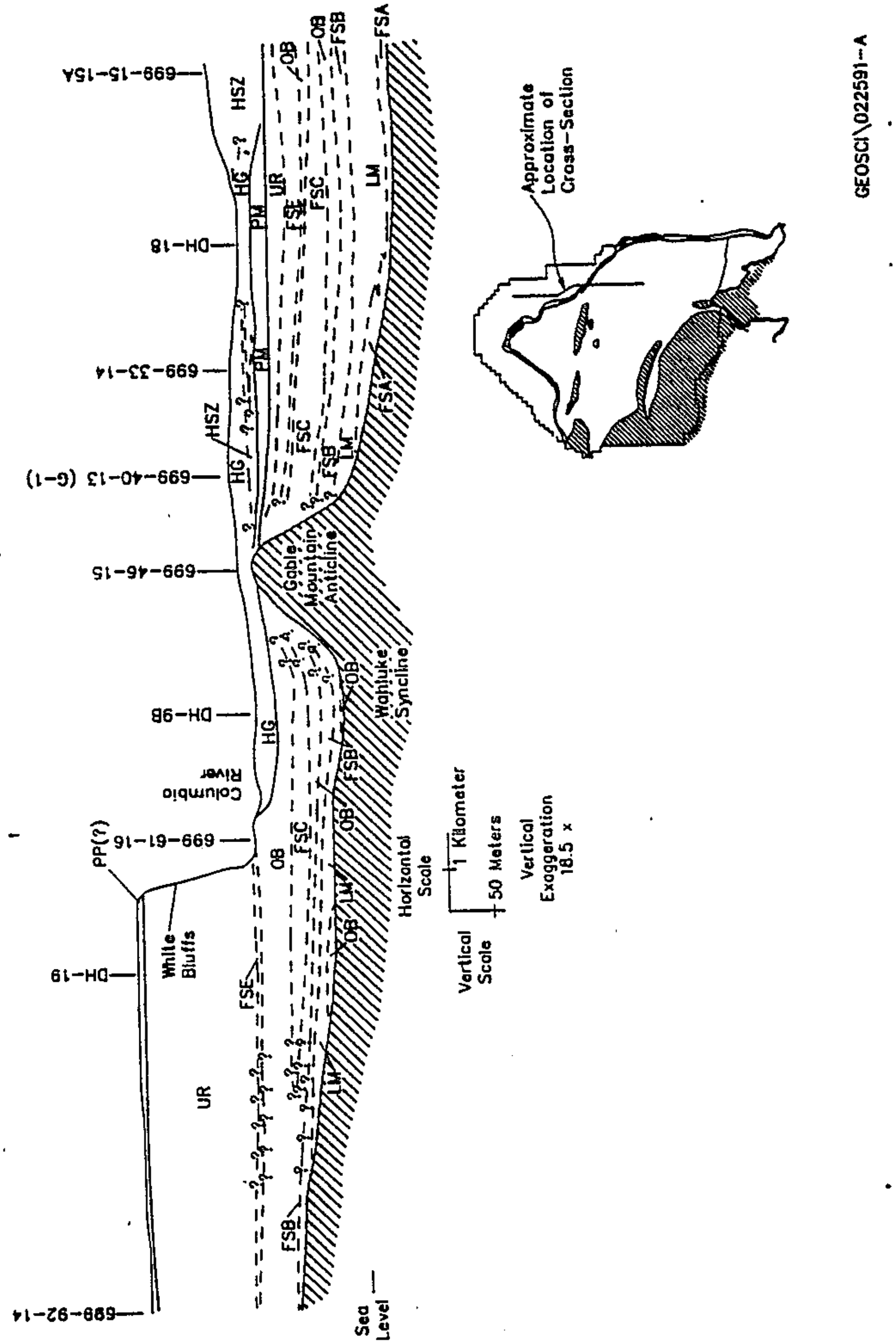

Figure 2-8. North-south Geologic Cross-section of the Suprabasalt Sediments Across the Eastern Wahluke Syncline and Gable Mountain Anticline. See Figure 2-5 for Explanation of Symbols and Abbreviations.

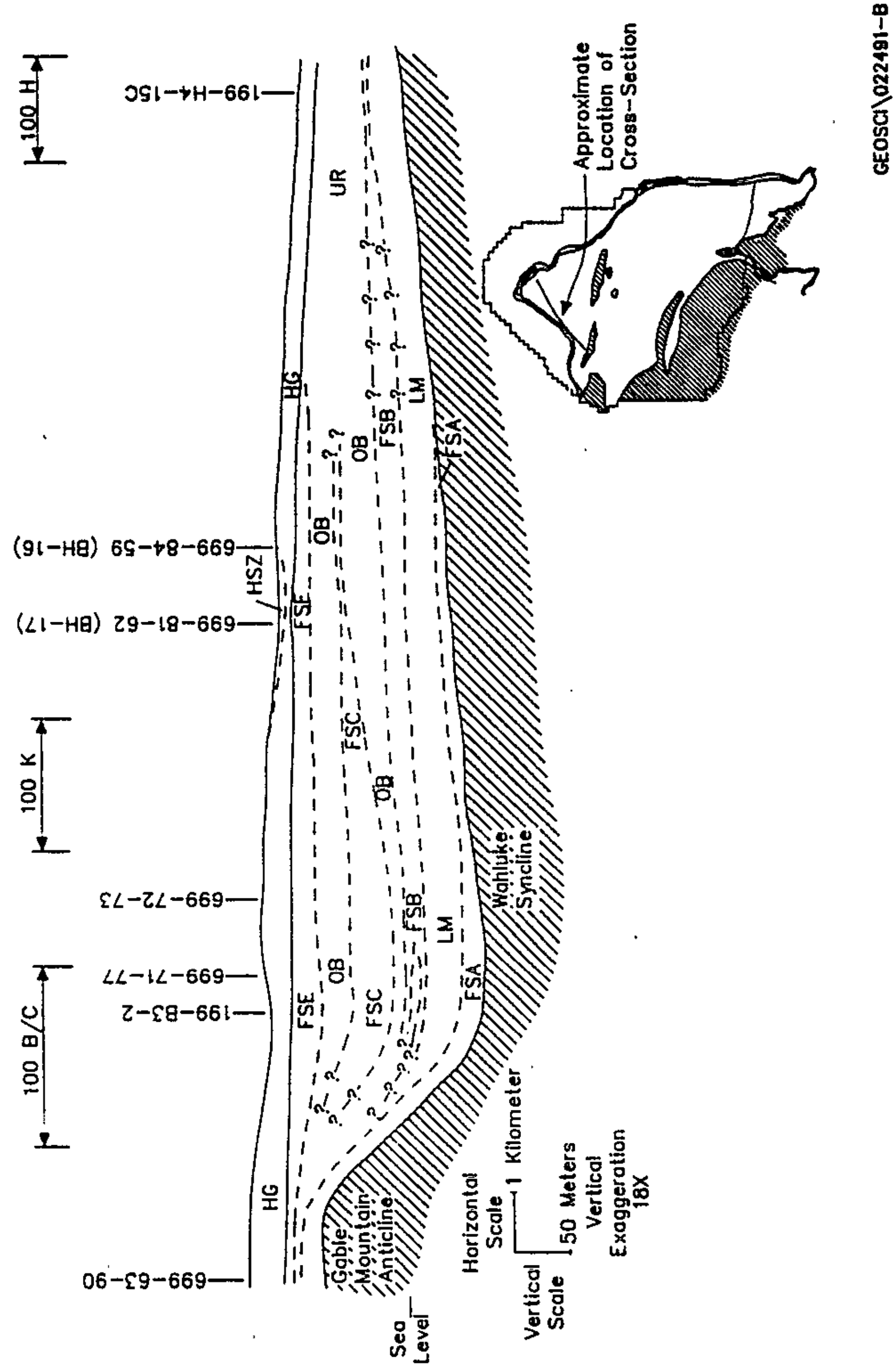

Figure 2-9. Northeast to Southwest Geologic Cross-section of the Suprabasalt Sediments Across the Western Wahluke Syncline in the Vicinity of the 100-B&C, 100-K, 100-N, and 100-H Areas. See Figure 2-5 for Explanation of Symbols and Abbreviations.

Unit FSA is overlain by as much as 140 ft (42 m) of overbank and lacustrine deposits designated the lower mud sequence. In the western Cold Creek syncline the lower mud sequence is 50 to 60 ft (15 to 18 m) thick and is dominated by overbank deposits. These overbank deposits pinch out in the east-central Cold Creek syncline south of 200 East Area where laterally extensive lacustrine-dominated strata dominate the lower mud sequence (Figures 2-6 and 2-7). The lower mud sequence thins onto the flanks of the Cold Creek syncline where it generally is dominated by thick overbank deposits underlying thin lacustrine deposits (Figures 2-7 and 2-8). In the Wahluke syncline the lower mud sequence overlies unit FSA in the west near 100-B&C, 100-K, and 100-N areas and basalt in the east near 100-H and 100-F areas (Figures 2-8 and 2-9). The lower mud sequence is equivalent to the fine-grained part of the basal unit and the lower unit of the Ringold Formation, respectively in the western Cold Creek syncline and 200 West Area as described in DOE (1988).

The lower mud sequence is overlain in most areas by the second fluvial gravel-dominated sequence, unit FSB. In the eastern Cold Creek syncline, unit FSB is up to 82 ft (25 m) thick; it pinches out in the central Cold Creek syncline, and it is not found at the 200 West and 200 East Areas (Figures 2-5 to 2-7). Unit FSB may be correlative to a localized gravel interval, designated unit FSD1, that overlies the lower mud sequence at the western end of the Cold Creek syncline (Figure 2-6). Fluvial gravel and basaltic gravel are found in unit FSD1. In the Wahluke syncline unit FSB is 10 to 72 ft (3 to 22 m) thick and coarsens from interbedded fluvial sand and overbank deposits in the west near 100-B&C Area to interbedded fluvial sand and gravel in the east near 100-F Area (Figures 2-8 and 2-9).

Deposits typical of the overbank facies association overlie unit FSB throughout the Hanford Site (Figures 2-5 to 2-9). Where unit FSB is absent these overbank deposits interfinger with the underlying lower mud sequence.

The fourth fluvial gravel-dominated interval, designated unit FSC, is found in a relatively narrow linear tract crossing the Pasco Basin from northwest to southeast. In the western Wahluke syncline near 100-B&C Area, unit FSC is up to 115 ft (35 m) thick; it is absent on the north limb of the syncline north of 100-N and 100-F areas, and thins and fines into the eastern Wahluke syncline south of 100-F Area where it consists of 50 to 66 ft (15 to 20 m) of fluvial sand (Figures 2-8 and 2-9). In the Cold Creek syncline unit FSC is dominated by fluvial gravel (Figures 2-5 to 2-7) and trends to the southeast in a linear tract stretching from east of 200 East Area to the vicinity of the city of Richland.

Where the top of unit FSC is preserved it is overlain by another overbank-dominated interval. Thin fluvial sands are present locally in these overbank deposits. Pedogenic alteration appears to be less well developed on the north flank of the Wahluke syncline north of 100-F Area where deposits are suggestive of a mix of the overbank and lacustrine facies associations.

It is unclear what the sequence of interbedded fluvial gravel (units FSB, FSD1, and FSC) and overbank deposits above the lower mud sequence are equivalent to. Because of the position of this sequence below gravel equivalent to the middle Ringold unit (described next), these interbedded deposits could be equivalent to the lower unit. However, the abundance of gravel differs so much from the generally accepted definition for the lower unit (DOE 1988) that such a correlation is questionable.

The uppermost fluvial gravel-dominated interval, designated unit FSE, is the most widespread of the five gravel intervals. Unit FSE is up to 98 ft (30 m) thick in the western Wahluke syncline near 100-B&C Areas while it pinches out north of 100-N Area and east of Gable Gap (Figures 2-8 and 2-9). Laterally equivalent strata in the vicinity of 100-F and 100-H areas consist of overbank deposits with minor intercalated fluvial sand. Unit FSE is found throughout the Cold Creek syncline forming a west thickening wedge 98 to 130 ft (30 to 40 m) thick south and east of 200 East Area and approximately 300 ft (90 m) thick south and west of 200 West Area (Figures 2-5 to 2-7). In the southeastern Cold Creek syncline near the 300 Area the overbank deposits underlying unit FSE are absent and the unit overlies or truncates underlying coarse intervals (unit FSC or FSB). Unit FSE correlates to the middle unit of the Ringold Formation in the 200 West Area as described by DOE (1988).

As much as 230 ft (70 m) of interbedded fluvial sand and overbank deposits overlie unit FSE in the White Bluffs south of Ringold Flats. Erosional remnants of these deposits are found in the south-central (south and east of 200 East Area) and western (200 West Area) Cold Creek syncline (Figures 2-5 to 2-7). Near 100-F and 100-H areas in the eastern Wahluke syncline, where FSE is absent, interbedded fluvial sands and overbank deposits grade into the overbank-dominated deposits overlying FSC (Figures 2-8 and 2-9). North of 100-F and 100-N areas, fluvial sands pinch out, and overbank deposits dominate all the way down to FSB (Figure 2-9).

The uppermost 210 to 230 ft (64 to 70 m) of the Ringold Formation consists of lacustrine deposits and intercalated fluvial sands. These strata do not occur in the subsurface at the Hanford Site; they are only found in the White Bluffs and locally on Rattlesnake Mountain. These lacustrine and the underlying fluvial sand and overbank deposits compose the upper unit of the Ringold Formation as originally defined by Newcomb (1958).

2.3.2 Post-Ringold Pre-Hanford Deposits

Thin alluvial deposits situated stratigraphically between the Ringold Formation and Hanford formation are found throughout the Pasco Basin. These deposits are referred to informally as: (1) Plio-Pleistocene unit, (2) pre-Missoula gravels, and (3) early "Palouse" soil.

2.3.2.1 Plio-Pleistocene Unit. Unconformably overlying the Ringold Formation in the western Cold Creek syncline in the vicinity of 200 West Area (Figures 2-5 and 2-6) is the laterally discontinuous Plio-Pleistocene unit (DOE 1988). The unit is up to 82 ft (25 m) thick and separated into two facies: (1) basaltic detritus and (2) pedogenic calcrete (Stage III and Stage IV). Depending on location, one or both facies may be present. The calcrete facies generally consists of interfingering carbonate-cemented silt, sand and gravel, and carbonate-poor silt and sand. The basaltic detritus facies consists of weathered and unweathered basaltic gravels deposited as locally derived slope wash, colluvium, and sidestream alluvium. The Plio-Pleistocene unit appears to be correlative to other sidestream alluvial and pedogenic deposits found near the base of the ridges bounding the Pasco Basin on the north, west, and south. These sidestream alluvial and pedogenic deposits are inferred to have a late Pliocene to early Pleistocene age on the basis of stratigraphic position and magnetic polarity of interfingering loess units.

2.3.2.2 Pre-Missoula Gravels. Quartzose to gneissic clast-supported pebble to cobble gravel with a quartzo-feldspathic sand matrix underlies the Hanford formation in the east-central Cold Creek syncline and at the east end of Gable Mountain anticline east and south of 200 East Area (Figures 2-5 to 2-8). These gravels, called the pre-Missoula gravels (PSPL 1982), are up to 82 ft (25 m) thick, contain less basalt than underlying Ringold gravels and overlying Hanford deposits, have a distinctive white or bleached color, and sharply truncate underlying strata. The nature of the contact between the pre-Missoula gravels and the overlying Hanford formation is not clear. In addition, it is unclear whether the pre-Missoula gravels overlie or interfinger with the early "Palouse" soil and Plio-Pleistocene unit. Magnetic polarity data indicate the unit is no younger than early Pleistocene in age (>1 Ma).

2.3.2.3 Early "Palouse" Soil. The early "Palouse" soil consists of up to 65 ft (20 m) of silt and fine-grained sand that overlies the Plio-Pleistocene unit in the western Cold Creek syncline around 200 West Area (Tallman et al. 1981; Bjornstad 1984; DOE 1988). Deposits composing the early "Palouse" soil are massive, brownish-yellow, and compact. These deposits are very loess-like in character. The unit is differentiated from overlying slackwater flood deposits by greater calcium carbonate content, massive structure in core, and high natural gamma response in geophysical logs (Bjornstad 1984). The upper contact of the unit is poorly defined, and it may grade up-section into the lower part of the Hanford formation. Based on a predominantly reversed polarity the unit is inferred to be early Pleistocene in age.

2.3.3 Hanford Formation

The Hanford formation consists of pebble to boulder gravel, fine- to coarse-grained sand, and silt. The Hanford formation consists of gravel-dominated deposits and deposits dominated by sand and silt. The gravel deposits range from well sorted to poorly sorted. The fine-grained deposits, which make up the most extensive and voluminous part of the Hanford formation, are divided into two facies: (1) plane-laminated sand and (2) normally graded rhythmites, also referred to as "Touchet Beds." The Hanford formation is commonly divided into two informal members: the Pasco gravels and the Touchet Beds (Myers et al. 1979; Tallman et al. 1981; Fecht et al. 1987; DOE 1988). The Pasco gravels generally correspond to the gravelly facies, and the Touchet Beds to the sandy to silty facies. The Hanford formation is thickest in the Cold Creek bar in the vicinity of the 200 Areas where it is up to 210 ft (65 m) thick (Figures 2-5 and 2-6). Hanford Site deposits are absent on ridges above approximately 1180 ft (360 m) above msl.

The gravel-dominated deposits (or facies) consist of coarse-grained sand and granule to boulder gravel that display massive bedding, plane to low-angle bedding, and large-scale cross-bedding in outcrop. Matrix commonly is lacking in these gravels, giving them an open framework appearance. Gravels dominate the Hanford formation in the 100 Areas north of Gable Mountain (Figures 2-8 and 2-9), the northern part of 200 East Area (Figure 2-5) and the eastern part of the Hanford Site including the 300 Area. In the 200 Areas the gravels generally fine to the south. The gravel-dominated facies were deposited by high-energy flood waters in or immediately adjacent to the main cataclysmic flood channelways.

The laminated sand facies consists of fine- to coarse-grained sand displaying plane lamination and bedding and less commonly plane and trough cross-bedding in outcrop. These sands may contain small pebbles or pebble-gravel interbeds less than 8 in. (20 cm) thick. The silt content of these sands is variable, but where it is low an open framework texture can be evident. The laminated sand facies is most common in the central Cold Creek syncline in the 200 Areas and it is transitional between the gravel-dominated facies to the north and the rhythmite facies to the south. The laminated sand facies was deposited adjacent to main flood channelways as it spilled out of the channelways, loosing competence.

The rhythmite facies consists of silt and fine- to coarse-grained sand that commonly display normally graded rhythmites a few centimeters to several tens of centimeters thick in outcrop (Myers et al. 1979; DOE 1988). Plane lamination and ripple cross-lamination is present in this facies. This facies is found throughout the central, southern, and western Cold Creek syncline within and south of 200 Areas. These sediments were deposited under slackwater conditions and in backflooded areas (DOE 1988).

Three episodes of cataclysmic flooding are recognized in the Pasco Basin. Based on reversed magnetic polarity, the oldest flood deposits antedate the Matuyama-Brunhes magnetic reversal, 770±20 Ka. Reversed-polarity flood gravels are exposed at several locations within the Channeled Scabland and at Poplar Heights, Vernita Grade, and Yakima Bluffs within the Pasco Basin.

At least one middle Pleistocene episode of cataclysmic flooding is indicated by poorly sorted gravel (with normal polarity) capped by platy to massive carbonate-plugged K horizons, characteristic of Stage III and Stage IV pedogenic carbonate development. A minimum age for this calcrete determined by Th/U dating is about 200 Ka. Fine-grained deposits inferred to be of this age contain paleosols with weekly developed B horizons. These flood deposits occur along the top of a prominant flood terrace at approximately 460 ft (140 m) elevation in the southern Pasco Basin northwest of Wallula Gap as well as elsewhere in the southern Pasco Basin.

Gravels associated with the last (late Wisconsin) episode of flooding are widespread throughout the Pasco Basin. These gravels are characterized by little or no soil development. Where pedogenic alteration has occurred it is limited to thin coatings of carbonate on the undersides of gravel clasts (Stage I carbonate development). Fine-grained deposits associated with the last flood commonly contain the Mount St. Helens set S tephra couplet, dated at approximately 13 Ka.

2.3.6 Holocene Surficial Deposits

Holocene surficial deposits consist of silt, sand, and gravel that form a thin (<16 ft [4.9 m]) veneer across much of the Hanford Site. These sediments were deposited by a mix of eolian and alluvial processes.

2.4 STRUCTURAL GEOLOGY AND TECTONIC SETTING

This section describes the tectonic framework and structural geology of the Hanford Site.

2.4.1 Tectonic Framework

The Columbia Plateau is a part of the North American continental plate and lies in a back-arc setting east of the Cascade Range. It is bounded on the north by the Okanogan Highlands, on the east by the Northern Rocky Mountains and Idaho Batholith, and on the south by the High Lava Plains and Snake River Plain.

2.4.2 Regional Structural Geology

The Columbia Plateau can be divided into three informal structural subprovinces (Figure 2-10): Blue Mountains, Palouse, and Yakima Fold Belt (Tolan and Reidel 1989). These structural subprovinces are delineated on the basis of their structural fabric, unlike the physiographic provinces that are defined on the basis of landforms. The Hanford Site is located near the junction of the Yakima Fold Belt and the Palouse subprovinces.

The principal characteristics of the Yakima Fold Belt are a series of segmented, narrow, asymmetric anticlines that have wavelengths between 3 and 19 mi (5 and 31 km) and amplitudes commonly less than 0.6 mi (1 km) (Reidel et al. 1989). These anticlinal ridges are separated by broad synclines or basins that, in many cases, contain thick accumulations of Neogene- to Quaternary-age sediments. The Pasco Basin is one of the larger structural basins in the Columbia Plateau.

The northern limbs of the generally east-west trending asymmetric anticlines of the Yakima Fold Belt dip steeply to the north or are vertical. The southern limbs generally dip at relatively shallow angles to the south. Thrust or high-angle reverse faults with fault planes that strike parallel or subparallel to the axial trends are principally found on the north sides of these anticlines. The amount of vertical stratigraphic offset associated with these faults varies but commonly exceeds hundreds of meters.

Deformation of the Yakima folds occurred under north-south compression and was contemporaneous with the eruption of the basalt flows (Reidel 1984; Reidel et al. 1989). The fold belt was enlarging during the eruption of the Columbia River Basalt Group and continued to enlarge through the Pliocene Epoch, into the Pleistocene Epoch, and perhaps to the present.

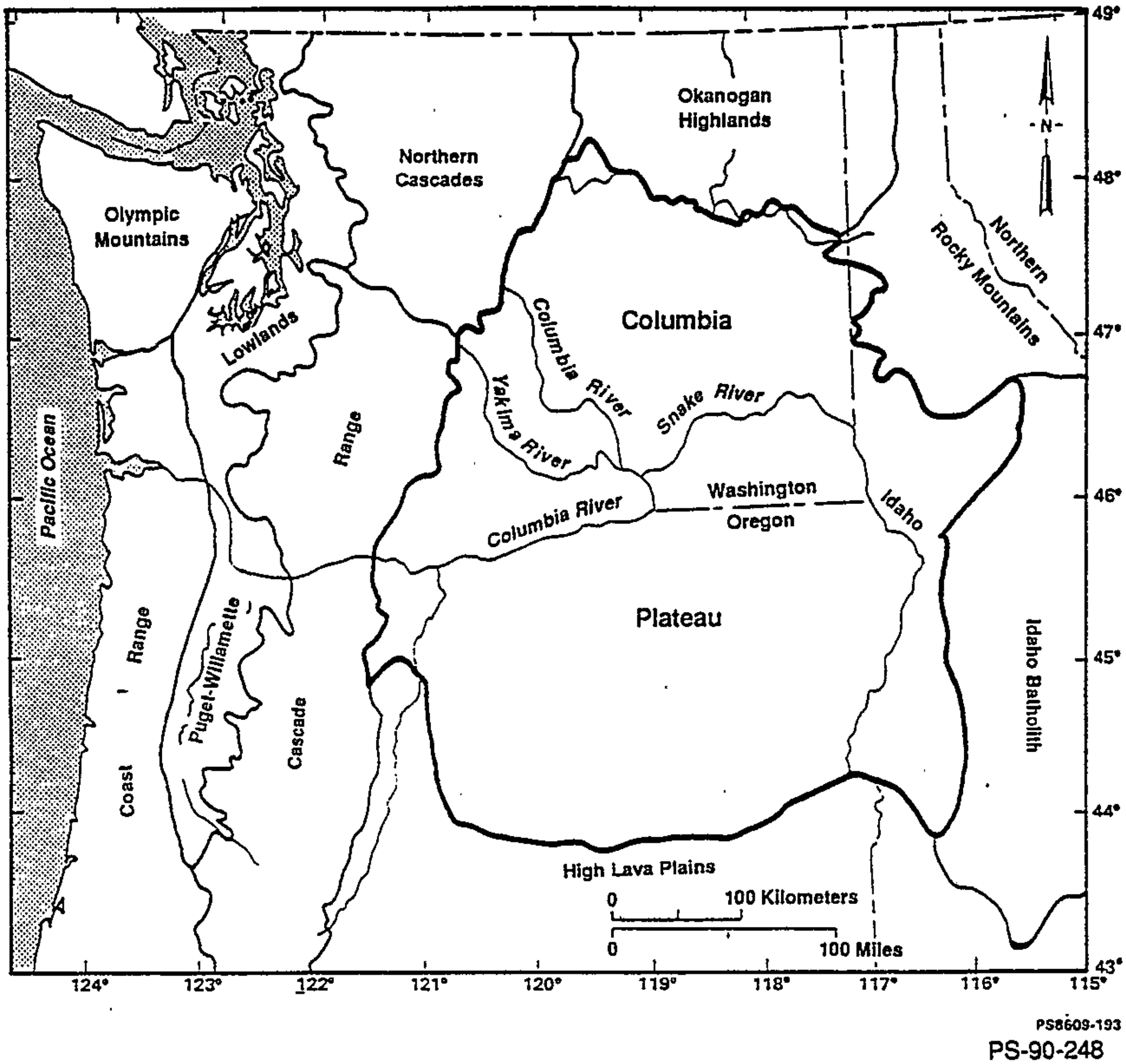

Figure 2-10. Structural Provinces of the Columbia Plateau.

2.4.3 Site Structural Geology

The Hanford Site is situated in the Pasco Basin, one of the largest structural basins on the Columbia Plateau. The Pasco Basin is bounded on the north by the Saddle Mountains anticline, on the west by the Umtanum Ridge, Yakima Ridge, and Rattlesnake Hills anticlines, and on the south by the Rattlesnake Mountain anticline (Figure 1-5). The Palouse slope, a west-dipping monocline, bounds the Pasco Basin on the east (Figure 1-5). The Pasco Basin is divided into the Wahluke and Cold Creek synclines by the Gable Mountain anticline, the easternmost extension of the Umtanum Ridge anticline.

The Cold Creek syncline (Figure 1-5) lies between the Umtanum Ridge-Gable Mountain uplift and the Yakima Ridge uplift, and is an asymmetric and relatively flat-bottomed structure. The 200 Areas lie on the northern flank, and the bedrock dips gently (approximately 5°) to the south. The 300 Area lies at the eastern end of the Cold Creek syncline where it merges with the Pasco syncline.

The Wahluke syncline (Figure 1-5) is the principal structural unit that contains the 100 Areas. The Wahluke syncline is an asymmetric and relatively flat-bottomed structure similar to the Cold Creek syncline. The northern limb dips gently (approximately 5°) to the south. The steepest limb is adjacent to the Umtanum-Gable Mountain structure.

The Umtanum Ridge-Gable Mountain structural trend is a segmented anticlinal ridge extending for a length of 85 mi (136 km) in an east-west direction and passes north of the 200 and 300 areas and south of the 100 Areas (Figures 1-5 and 2-1). This structure consists of five segments. From the west, the Umtanum Ridge plunges eastward and joins the Gable Mountain-Gable Butte segment just east of the western boundary of the Hanford Site. The easternmost segment, the southeast anticline, trends southeast off the eastern boundary of the Gable Mountain-Gable Butte segment.

Umtanum Ridge is an asymmetrical, north-vergent-to-locally overturned anticline with a major thrust to high-angle reverse fault on the north side (Goff 1981; NRC 1982; PSPL 1982; Price and Watkinson 1989) that dies out eastward toward Gable Mountain. Gable Mountain and Gable Butte are two topographically isolated, anticlinal ridges that are composed of a series of northwest trending, doubly plunging, en echelon anticlines, synclines, and associated faults. Capable faulting has been identified on Gable Mountain (NRC 1982; PSPL 1982).

The Yakima Ridge uplift extends from west of Yakima, Washington, to the center of the Pasco Basin, where it forms the southern boundary of the Cold Creek syncline (Figure 2-1). The easternmost surface expression of the Yakima Ridge uplift is represented by an anticline that plunges eastward into the Pasco Basin (Myers and Price 1979, Plate III; Tolan and Reidel 1989). The eastern extension of Yakima Ridge is mostly buried beneath late Cenozoic sediments but is assumed to be similar to the exposed parts.

The 200 and 300 areas are situated on the south flank of the Umtanum-Gable Mountain anticline where the Miocene-aged basalt bedrock dips to the southwest into the Cold Creek syncline. The 100 Areas lie north of the Umtanum-Gable Mountain anticline in the Wahluke syncline. The deepest parts of the Cold Creek syncline, the Wye Barricade depression and the Cold Creek depression, are approximately 7.5 mi (12 km) southeast of the 200 Areas and under the 200 West Area, respectively.

2.5 SEISMOLOGY

This section describes the seismology of the Hanford Site. Westinghouse Hanford Company (Westinghouse Hanford) operates a 20-station seismic network in and around the Hanford Site for the U.S. Department of Energy (DOE). Earthquakes with a magnitude of 1.5 or greater can be accurately located with this array.

Eastern Washington and especially the Columbia Plateau region is a seismically inactive area when compared to the rest of the western United States (DOE 1988). The closest regions of historic moderate-to-large earthquake generation are in western Washington and Oregon and western Montana and eastern Idaho. The most significant event relative to the Hanford Site is the 1936 Milton-Freewater, Oregon, earthquake that had a magnitude of 5.75 and that occurred more than 54 mi (90 km) away. The largest Modified Mercalli Intensity was felt at Walla Walla, Washington, and was VII. This event was approximately 63 mi (105 km) from the Hanford Site.

Since mid-1969 there has been a Hanford seismic network capable of locating all earthquakes of Richter Magnitude 1.5 and larger at or near the Hanford Site, and magnitude 2.0 and larger throughout the rest of southeastern Washington. The historic seismic record for eastern Washington began in approximately 1850, and no earthquakes large enough to be felt had epicenters on the Hanford Site. The only evidence of past moderate or possibly large earthquake activity is geologic evidence. This evidence is shown by the anticlinal folds and faulting associated with Rattlesnake Mountain, Saddle Mountain, and Gable Mountain. The currently recorded seismic activity related to these structures consists of micro-size earthquakes. The suggested recurrence rates of moderate and larger-size earthquakes on and near the Hanford Site are measured in geologic time (tens of thousands of years).

3.0 REGIONAL AND HANFORD SITE HYDROLOGY

3.1 REGIONAL SURFACE HYDROLOGY

Surface drainage enters the Pasco Basin from several other basins that include the Yakima River Basin, Horse Heaven Basin, Walla Walla River Basin, Palouse/Snake Basin, and Big Bend Basin (Figure 3-1). Within the Pasco Basin, the Columbia River is joined by major tributaries including the Yakima, Snake, and Walla Walla rivers. No perennial streams originate within the Pasco Basin. Columbia River inflow to the Pasco Basin is recorded at the U.S. Geological Survey (USGS) gage below Priest Rapids Dam, and outflow is recorded below McNary Dam. Average annual flow at these recording stations is approximately 8.7×10^7 acre-ft at the USGS gage and 1.3×10^8 acre-ft at the McNary Dam gage (DOE 1988).

Total estimated precipitation over the basin averages less than 6.2 in./yr (15.8 cm/yr). Mean annual runoff from the basin is estimated to be less than 2.5×10^4 acre-ft/yr, or approximately 3% of the total precipitation. The remaining precipitation is assumed to be lost through evapotranspiration with a small component (perhaps less than 1%) recharging the groundwater system (DOE 1988).

3.2 SURFACE HYDROLOGY OF THE HANFORD SITE

Primary surface-water features associated with the Hanford Site are the Columbia River and its major tributaries, the Yakima, Snake, and Walla Walla rivers. West Lake, about 10 acres in size and less than 3 ft deep, is the only natural lake within the Hanford Site (DOE 1988). Wastewater ponds, cribs and ditches associated with nuclear fuel processing and waste disposal activities are also present on the Hanford Site (Figure 3-2).

The Columbia River flows through the northern part of the Hanford Site and along the eastern border of the Site. This section of river, the Hanford Reach, extends from Priest Rapids Dam to the headwaters of Lake Wallula (the reservoir behind McNary Dam). Flow along the Hanford Reach is controlled by Priest Rapids Dam. Several drains and intakes are also present along this reach, including irrigation outfalls from the Columbia Basin Irrigation Project, the Washington Public Power Supply System Nuclear Project 2, and Hanford Site intakes for onsite water use.

Routine water-quality monitoring of the Columbia River is conducted by DOE for both radiological and nonradiological parameters and has been reported by Pacific Northwest Laboratory since 1973. Washington State Department of Ecology (Ecology) has issued a Class A (excellent) quality designation for Columbia River water along the Hanford Reach from Grand Coulee Dam, through the Pasco Basin, to McNary Dam. This designation requires that all industrial uses of this water be compatible with other uses, including drinking, wildlife habitat, and recreation. In general, the Columbia River water is characterized by a very low suspended load, a low nutrient content, and an absence of microbial contaminants (DOE 1988).

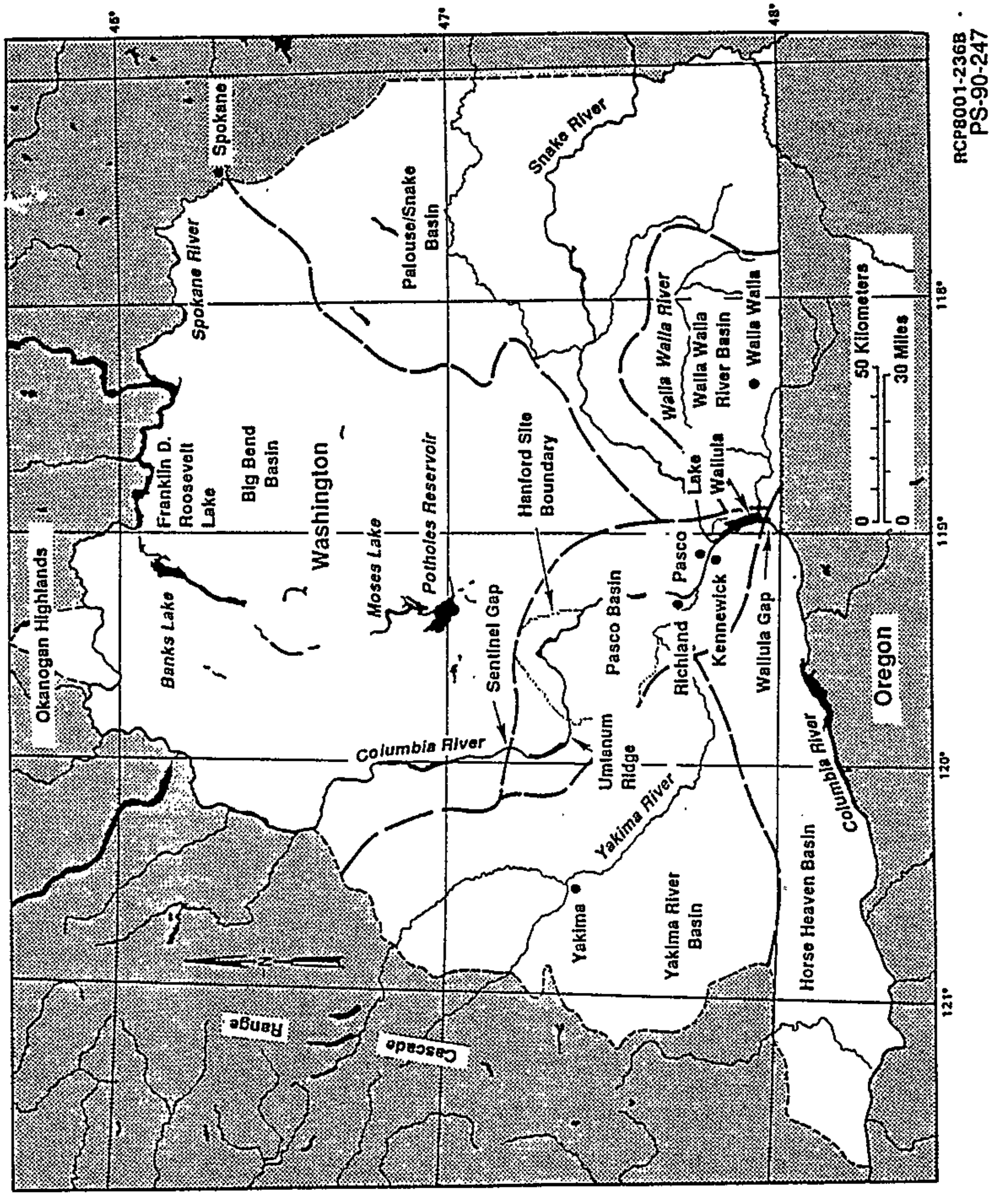

Figure 3-1. Hydrologic Basins Designated for the Washington State Portion of the Columbia Plateau (DOE 1988).

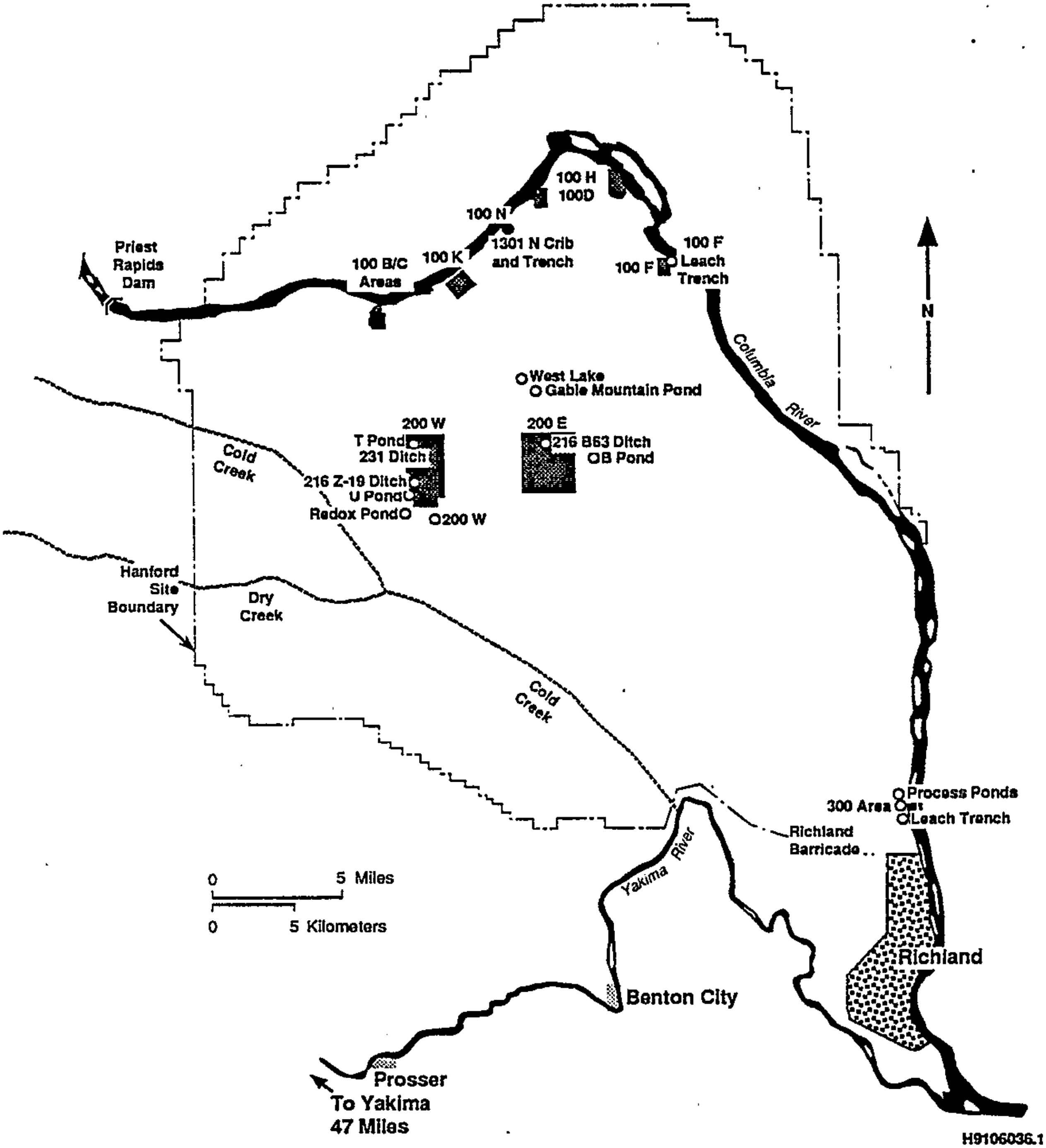

Figure 3-2. Location of Water Disposal Ponds on the Hanford Site.

Approximately one-third of the Hanford Site is drained by the Yakima River system. Cold Creek and its tributary, Dry Creek, are ephemeral streams within the Yakima River drainage system. Both streams drain areas along the western part of the Hanford Site and cross the southwestern part of the Site toward the Yakima River. Surface flow, which may occur during spring runoff or after heavier-than-normal precipitation, infiltrates and disappears into the surface sediments. Rattlesnake Springs, located on the western part of the Site, forms a small surface stream that flows for about 1.8 mi (2.9 km) before infiltrating into the ground.

3.3 REGIONAL SUBSURFACE HYDROLOGY

The hydrogeology of the Pasco Basin is characterized by a multiaquifer system that consists of four hydrogeologic units that correspond to the upper three formations of the Columbia River Basalt Group (Grande Ronde Basalt, Wanapum Basalt, and Saddle Mountains Basalt) and the suprabasalt sediments. The basalt aquifers consist of the tholeiitic flood basalts of the Columbia River Basalt Group and relatively minor amounts of intercalated fluvial and volcaniclastic sediments of the Ellensburg Formation. Confined zones in the basalt aquifers are present in the sedimentary interbeds and/or interflow zones that occur between dense basalt flows. The main water-bearing portions of the interflow zones are networks of interconnecting vesicles and fractures of the flow tops and flow bottoms (DOE 1988). The suprabasalt sediment or uppermost aquifer system consists of fluvial, lacustrine, and glaciofluvial sediments. This aquifer is regionally unconfined and is contained largely within the Ringold Formation and Hanford formation. Table 3-1 presents hydraulic parameters for various water-bearing geologic units at the Hanford Site.

Local recharge to the shallow basalt aquifers results from infiltration of precipitation and runoff along the margins of the Pasco Basin, and in areas of artificial recharge where a downward gradient from the unconfined aquifer system to the uppermost confined basalt aquifer may occur. Regional recharge of the deep basalt aquifers is inferred to result from interbasin groundwater movement originating northeast and northwest of the Pasco Basin in areas where the Wanapum and Grande Ronde Basalts crop out extensively (DOE 1988). Groundwater discharge from shallow basalt aquifers is probably to the overlying aquifers and to the Columbia River. The discharge area(s) for the deeper groundwater system is uncertain, but flow is inferred to be generally southeastward with discharge thought to be south of the Hanford Site (DOE 1988).

Erosional "windows" through dense basalt flow interiors allows direct interconnection between the uppermost aquifer system and underlying confined basalt aquifers. Graham et al. (1984) reported that some contamination was present in the uppermost confined aquifer (Rattlesnake Ridge interbed) south and east of Gable Mountain Pond. Graham et al. (1984) evaluated the hydrologic relationships between the Rattlesnake Ridge interbed aquifer and the unconfined aquifer in this area and delineated a potential area of intercommunication beneath the northeast portion of the 200 East Area.

Table 3-1. Hydraulic Parameters for Various Areas and Geologic Units at the Hanford Site.

Location	Interval tested	Hydraulic conductivity (ft/d)	Transmissivity (ft^2/d)	Effective porosity	Data source
100 Area	Rattlesnake Ridge Interbed	0 - 100		<10%	Gephart et al. (1979)
Hanford Site	Saddle Mountain Basalt Flowtop	10^{-2} - 10^{-6}		5%	Cushing (1989)
100 Area	Ringold Formation FSE	29 - 1,297	5,750 - 26,700		Liikala et al. (1988)
200 Area	Rattlesnake Ridge Interbed		8 - 1,165		Graham et al. (1981, 1984)
200 East Area	Elephant Mountain Interflow Zone		7.5 - 6,120		Graham et al. (1984)
Hanford Site	Selah Interbed		3×10^{-5}		Graham et al. (1984)
200 West Area	Ringold Formation FSE	0.6 - 200			Last et al. (1989)
1100 Area	Ringold Formation FSC/FSB	3×10^{-1} - 5			Lindberg and Bond (1979)
1100 Area	Ringold Formation Overbank Deposits	8×10^{-4} - 1×10^{-1}			Lindberg and Bond (1979)
300 Area	Levey Interbed	0.01 - 1,000			DOE/RL (1990)
300 Area	Ringold Formation	1.9 - 10,000			DOE/RL (1990)
300 Area	Hanford formation	11,000 - 50,000			DOE/RL (1990)

The uppermost aquifer system is regionally unconfined beneath the Hanford Site and lies at depths ranging from less than 1 ft below ground surface near West Lake and the Columbia and Yakima Rivers, to greater than 350 ft (106.7 m) in the central portion of the Cold Creek syncline. Groundwater in this aquifer system occurs within the glaciofluvial sands and gravels of the Hanford formation and the fluvial/lacustrine sediments of the Ringold Formation. Ringold sediments are divided into five lithofacies: (1) fluvial gravel, (2) fluvial sand, (3) overbank deposits consisting of silt and sand, (4) lacustrine deposits, and (5) basaltic debris flow gravel. Stratigraphic divisions of these units are discussed in detail in the suprabasalt sediments geology section (Section 2.3).

The position of the water table in the southwestern Pasco Basin is generally within Ringold fluvial gravels of unit FSE (see section 2.3.1). In the northern and eastern Pasco Basin the water table is generally within the Hanford formation. Hydraulic conductivities for the Hanford formation (2,000 to 10,000 ft/d; 609.7 to 3,048 m/d) are much greater than those of the gravel facies of the Ringold Formation (610 to 3,050 ft/d; 185.9 to 929.6 m/d) (Graham et al. 1981). The main body of the unconfined aquifer generally occurs within the Ringold Formation.

The base of the uppermost aquifer system is defined as the top of the uppermost basalt flow. However, fine-grained overbank and lacustrine deposits in the Ringold Formation locally form confining layers for Ringold fluvial gravels (units FSA, FSB, FSD1, FSC) underlying unit FSE. The uppermost aquifer system is bounded laterally by anticlinal basalt ridges and is approximately 500 ft (152.4 m) thick near the center of the Pasco Basin.

Sources of natural recharge to the uppermost aquifer system are rainfall and runoff from the higher bordering elevations, water infiltrating from small ephemeral streams, and river water along influent reaches of the Yakima and Columbia rivers. The movement of precipitation through the unsaturated (vadose) zone has been studied at several locations on the Hanford Site (Gee 1987; Routson and Johnson 1990; Rockhold et al. 1990). Conclusions from these studies vary. Gee (1987) and Routson and Johnson (1990) concluded that no downward percolation of precipitation occurs on the 200 Areas Plateau where the sediments are layered and vary in texture, and that all moisture penetrating the soil is removed by evapotranspiration. Rockhold et al. (1990) suggested that downward water movement below the root zone is common in the 300 Area, where soils are coarse-textured and precipitation was above normal.

Artificial recharge of the uppermost aquifer system occurs from the disposal of large volumes of wastewater on the Hanford Site (principally in the 200 Areas), and from large irrigation projects surrounding the Hanford Site. Figures 3-3 and 3-4 illustrate the groundwater table for the Hanford Site during the periods January 1944 and June 1989. Effluent disposal at the Hanford Site altered these hydraulic gradients and flow directions. Before operations at the Hanford Site began in 1944, the hydraulic gradient in all but the southwestern-most portion of the Hanford Site was approximately 5 ft/mi (1.5 m/km). Regional groundwater flow was generally toward the east-northeast, although flow north of Gable Mountain was more to the north. Groundwater flow north of Gable Mountain now trends in a more northeasterly direction as a result of mounding near reactors and flow through Gable Gap. South of Gable Mountain, flow is interrupted locally by the groundwater mounds in the 200 Areas. There is also a component of groundwater flow to the north between Gable Mountain and Gable Butte from the 200 Areas.

Wastewaters discharged on the Hanford Site have reached the unconfined aquifer and the confined aquifer of the Rattlesnake Ridge interbed. The primary constituents that have reached the upper confined aquifer and the uppermost aquifer system are tritium, iodine-129, ruthenium-106, technetium-99, uranium, nitrate, and chromium (DOE 1986). The groundwater is routinely and extensively monitored to record the movement of contaminants and to determine any impact from the Site to the public. Groundwater monitoring reports are produced annually (e.g., Serkowski and Jordan 1989).

Temporary reversal of groundwater flow entering the Columbia River may occur during transient, high-river stages. This occurrence is known as bank storage. Correlations were made between groundwater level and river-stage fluctuations along a 50-mi (81-km) reach of the Columbia River adjacent to the Hanford Site by Newcomb and Brown (1961). They concluded that a 100 mi^2 (260 km^2) area within the Hanford Site was affected by bank storage. During a 45-d rise in river stage, it was estimated that water infiltrated at an

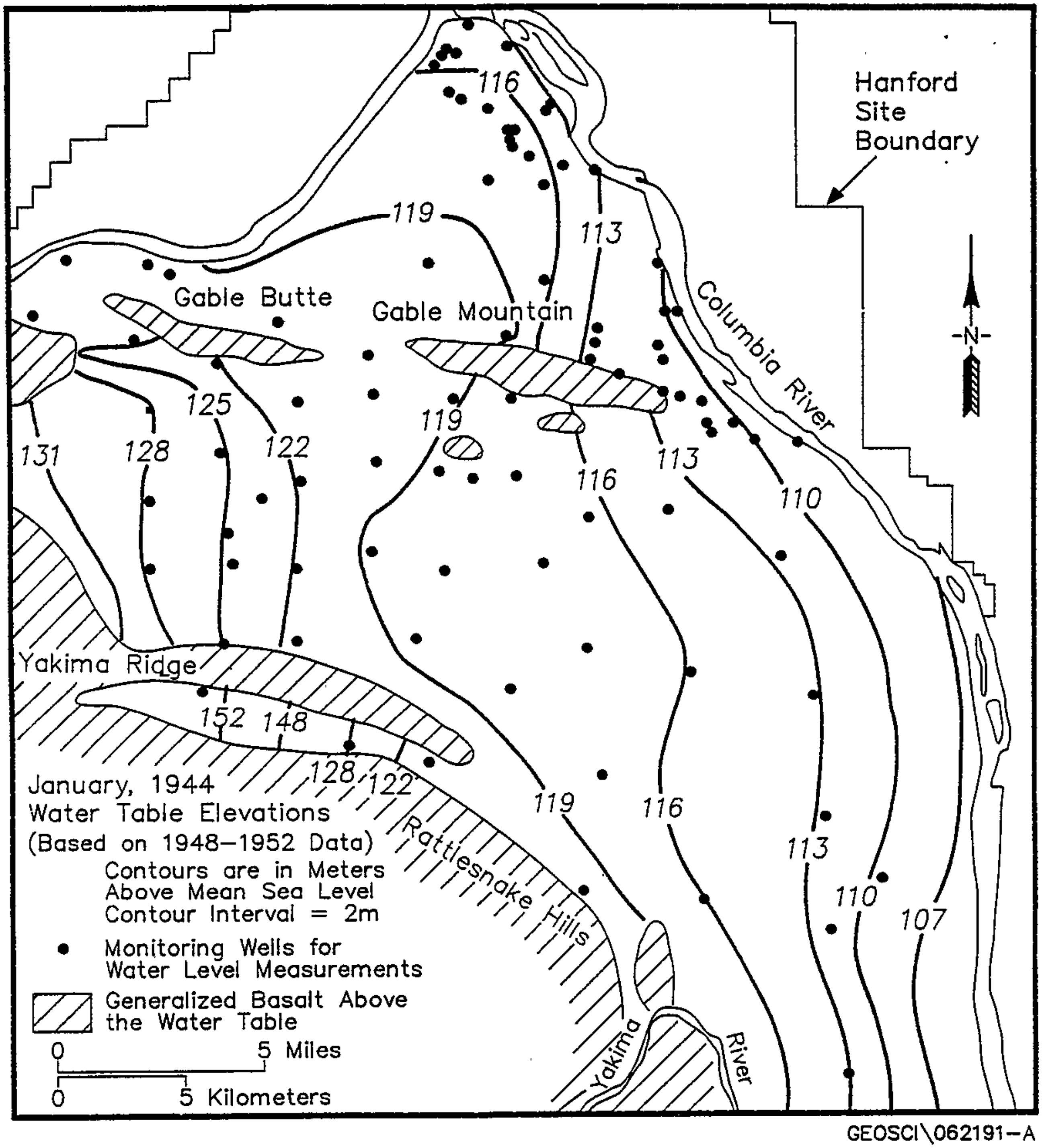

Figure 3-3. Hindcast Water Table Map of the Hanford Site, January 1944 (ERDA 1975).

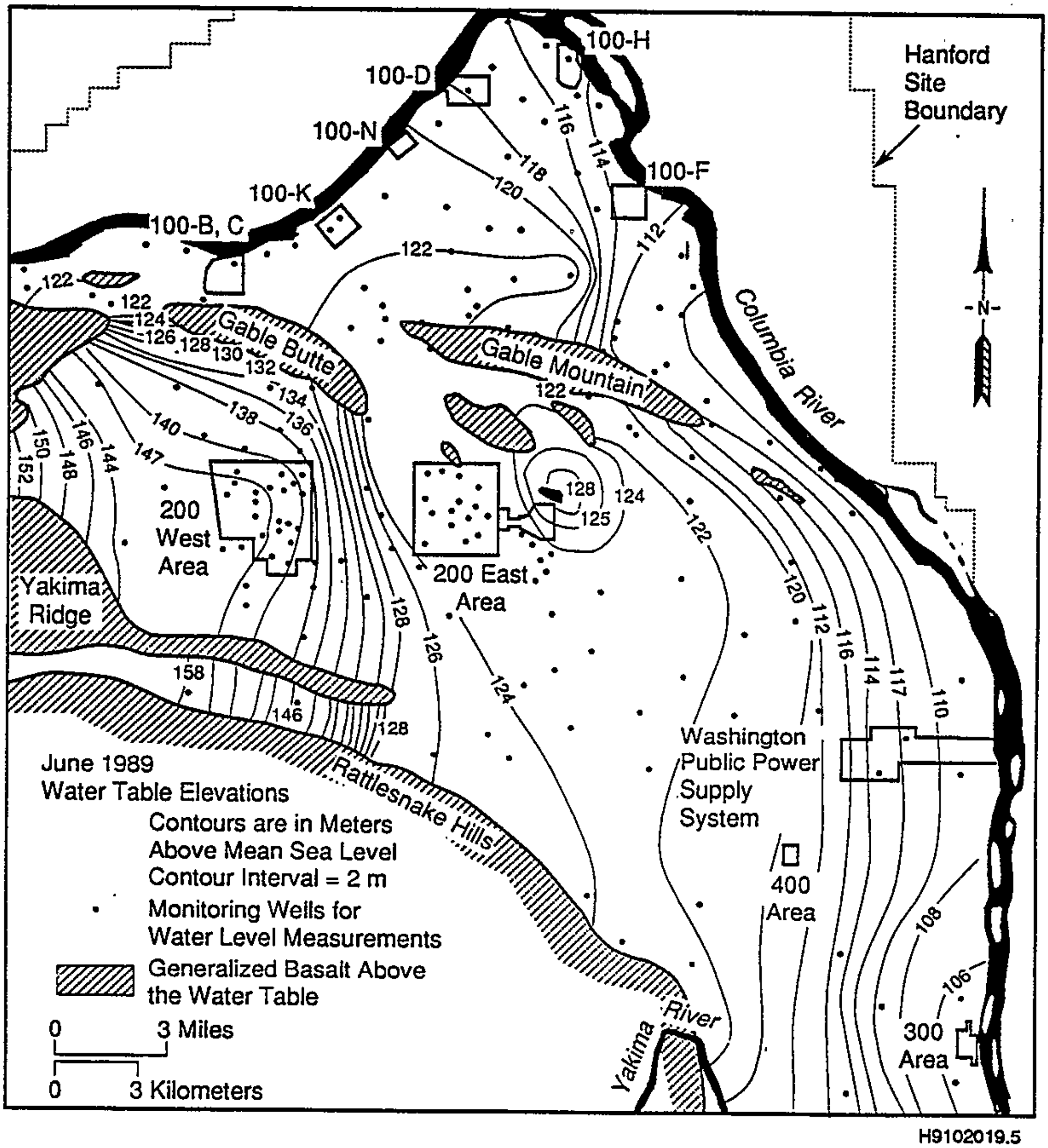

Figure 3-4. Hanford Site Water Table Map, June 1989 (Smith et al. 1990).

average rate of 3,700 acre-ft/d versus 1,000 acre-ft/d during the 165-d recession period (time between consecutive storage events). Since this study was conducted, dam control on the Columbia River has reduced the magnitude of bank storage on the groundwater system.

3.4 HYDROGEOLOGY OF THE OPERATIONAL AREAS

In the past, emphasis has been placed on geologic-hydrogeologic data acquisition and interpretation, specifically in waste disposal areas at the Hanford Site. Therefore, available hydrogeologic data is concentrated within the 100, 200, 300, and 1100 areas. This section discusses the hydrogeology of each of these areas.

3.4.1 100 Area

The 100 Areas are located along the Columbia River north of Gable Mountain. The general hydrogeologic column for 100-N Area, shown in Figure 3-5, illustrates the relationship between hydrogeologic and geologic facies designations. The major hydrostratigraphic units are the (1) Rattlesnake Ridge interbed, (2) Elephant Mountain Basalt Member, (3) Ringold Formation, and (4) Hanford formation. Aquifers below the Rattlesnake Ridge interbed are not discussed because the more significant water-bearing intervals relating to environmental issues are those closer to ground surface. Two semiconfined water-bearing intervals are found in the generally unconfined Hanford and Ringold-dominated uppermost aquifer system. The aquifer in the basalts is a confined system.

Except for the 100-H and 100-N areas, little hydrogeologic characterization has been undertaken in the 100 Areas. In the following discussion the 100-N Area will be examined in detail, and where data is available, 100-N hydrogeology will be related to other 100 Areas. However, because of the lack of data at these other locations, detailed discussion of hydrogeology of these areas is not possible.

The Rattlesnake Ridge interbed is the uppermost confined aquifer and consists of 45 to 60 ft (13.7 to 18.3 m) of tuffaceous siltstone and sandstone. Reported hydraulic conductivities range from 10^{-7} to 10^{-2} ft/d (3.0×10^{-8} to 3.0×10^{-3} m/d) for interbeds of the Saddle Mountains Basalt. However, reported mean hydraulic conductivities for the Rattlesnake Ridge interbed range from 0 to 100 ft/d (30.5 m/d) (Gephart et al. 1979). Storativity values range from 10^{-3} to 10^{-4} with an effective porosity of less than 10% (DOE/RL 1988). Potentiometric data are not available for this interbed in the 100 Areas, although at other locations at the Hanford Site, there is an upward vertical gradient between the Rattlesnake Ridge interbed aquifer and the uppermost aquifer system. Storage coefficients have not been reported in the 100 Areas but may range from 0.01 to 0.1 as measured elsewhere at the Hanford Site (Gephart et al. 1979). This aquifer probably occurs beneath all of the 100 Areas.

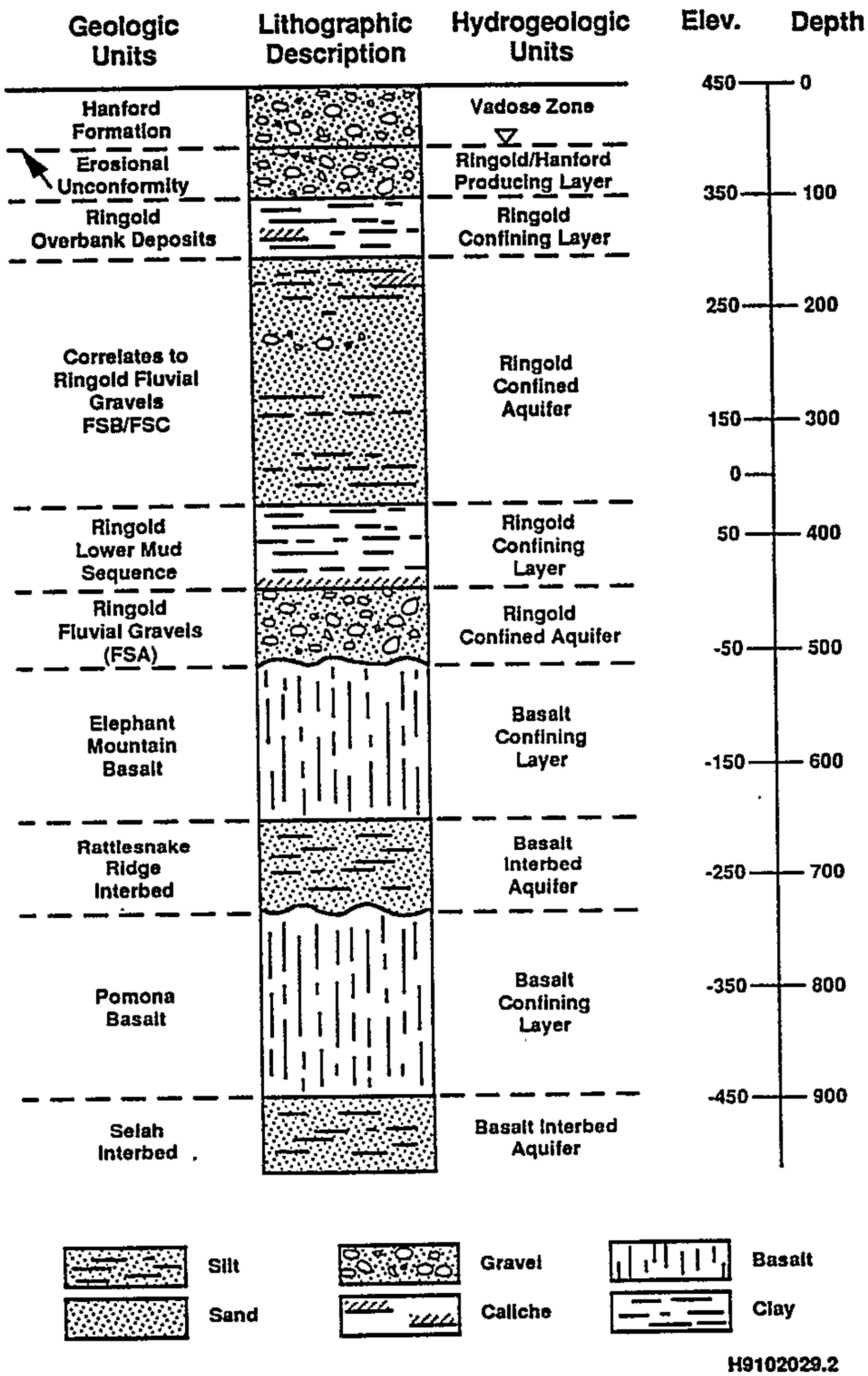

Figure 3-5. Conceptual Geologic and Hydrogeologic Column for the 100 Areas.

The Elephant Mountain Basalt Member, which is found throughout the 100 Areas, forms a confining layer above the Rattlesnake Ridge interbed. The Elephant Mountain Basalt Member has some vesicular zones, but because the Member is more than 100 ft thick, vertical flow is assumed to be minimal. Reported hydraulic conductivities for Saddle Mountains Basalt flow tops at the Hanford Site range from 10^{-2} to 10^{-6} ft/d (3.0×10^{-3} to 3.0×10^{-7} m/d) and the reported effective porosity is approximately 5% (Cushing 1989). No data are available for Saddle Mountains Basalt flow interiors, but for interior zones of the Wanapum and Grande Ronde basalts, conductivities range from 10^{-6} ft/d for the 100 Areas (DOE/RL 1990b) to 10^{-8} ft/d (3.0×10^{-7} to 3.0×10^{-9} m/d), with effective porosities of less than 1% (Cushing 1989). The only hydraulic conductivity value available for the Elephant Mountain Basalt Member (2,040 ft/d; 621.8 m/d) is assumed to be representative of a very permeable zone in the basalt (Gephart et al. 1979).

At the 100-N Area the uppermost aquifer system consists of five hydrostratigraphic units (Figure 3-4). The lowest unit consists of the fluvial gravel of Ringold unit FSA that lies unconformably above the Elephant Mountain Basalt. Unit FSA consists of interbedded sand and cobbles with some caliche and ranges in thickness from 18 to 65 ft (5.5 to 19.8 m). No hydrologic data are available for unit FSA at 100-N Area, but hydraulic conductivities in other areas of the Hanford Site range from 0.01 to 1,000 ft/d (3.0×10^{-3} to 305 m/d) (DOE 1988; Schalla et al. 1988). Unit FSA is not found at 100-F, 100-H, and 100-D areas.

The confining layer above unit FSA consists of 100 to 150 ft (30.5 to 45.7 m) of interbedded clay and silt assigned to the lower mud sequence of the Ringold Formation. No hydrologic data are available for this layer in the 100 Areas. However, reported horizontal hydraulic conductivity values for this sequence elsewhere range from 0.11 to 10 ft/d (.03 to 3.1 m/d) (DOE 1988). The vertical hydraulic conductivity for this layer is approximately 10^{-8} ft/d (3.0×10^{-9} m/d) (Liikala et al. 1988). These fine-grained sediments are continuous across the 100 Areas.

Silty sand to sandy silt equivalent to Ringold units FSB and FSC composes the third hydrostratigraphic unit. The third unit is 175 to 200 ft (53.3 to 61 m) thick. Stratigraphic trends (consisting of alternating lithologies) in this unit suggest there may be alternating producing and confining layers. The hydrologic properties of this unit have not been determined, although hydraulic conductivity values in the 0.1 to several hundred feet per day (0.03 to 61 m/d) range may be expected. This hydrostratigraphic unit coarsens toward the southwest near 100-K and 100-B&C areas and fines toward the southeast in the vicinity of 100-H and 100-F areas.

The fourth hydrostratigraphic unit at the 100-N Area is a confining interval that consists of interbedded overbank clay and silt with occasional thin sand layers. This interval ranges in thickness from 10 to 50 ft (3.1 to 15.2 m). No transmissivity or hydraulic conductivity data are available for the interval, but the clay and silt are expected to restrict both vertical and horizontal movement of groundwater and contaminants. This confining interval is continuous across the 100 Areas.

The uppermost hydrostratigraphic unit is unconfined and occurs in the fluvial gravels of Ringold unit FSE and locally the bottom few feet of the Hanford formation. Channels and other erosive features cut into the top of the Ringold Formation and filled by higher-permeability Hanford Site deposits probably act as preferred pathways for groundwater movement. Hydraulic conductivities for the upper hydrostratigraphic unit vary from 290 to 1,297 ft/d (88.4 to 395.3 m/d) and transmissivity ranges from 5,750 to 26,700 ft^2/d (534 to 2,481 m^2/d) (Liikala et al. 1988). The water table typically is located 10 to 130 ft (3 to 40 m) below land surface, and the upper hydrostratigraphic unit ranges in thickness from 0 to 40 ft (0 to 12 m) throughout the 100 Areas, thickening in the 100-K and 100-B&C areas. In the vicinity of 100-H and 100-F areas, Ringold unit FSE is absent, and the unit consists entirely of Hanford Site gravels. The water table gradient is approximately 2 to 5 ft/mi (0.6 to 1.5 m/km). Regionally, groundwater flows across the area in a northeasterly to easterly direction, and discharges are to the Columbia River. Locally in the 100-K, 100-N, and 100-D areas, groundwater flow is to the northwest toward the Columbia River. Figure 3-6 shows water table elevations for the 100 Areas for the period June 1990. The Columbia River stage was unusually high during June 1990; consequently, a reverse gradient is seen along the riverbank during that time period.

The unsaturated (vadose) zone at the 100-N Area and throughout the 100 Areas occurs in the Hanford formation and ranges up to 130 ft (39.6 m) in thickness (Jensen 1987; Gilmore 1989). The vadose zone has decreased in thickness historically because of groundwater mounding. Vadose sediments consist of poorly sorted gravel, sand, and silt. The moisture content at depth in unsaturated sediments at the Hanford Site is generally low, ranging from 2% to 7% in coarse and medium-grained soils and 7% to 15% in silts (Gee and Heller 1985). The presence of perched water was noted during recent drilling at 100-N Area, but no other indication of perched water has been noted.

Historically, groundwater flow in the 100 Areas has been dominated by the groundwater mounds resulting from discharge of reactor effluents to the subsurface. Artificial recharge of the aquifer has altered gradients and flow directions (Golder Associates, Inc. 1988 and 1990). Water levels were highest in July 1965 during the peak of effluent releases. These elevated water levels generated numerous springs along the bank of the Columbia River (Crews and Tillson 1969). Currently, all groundwater mounds in the 100 Areas associated with effluent discharge have dissipated. Seasonal changes in groundwater flow have not been readily apparent from water table maps.

In addition to artificial recharge, groundwater flow in the 100 Areas is influenced by bank storage near the Columbia River. River stage routinely fluctuates as much as 5 ft (1.5 m) during a 24-h period resulting from releases from Priest Rapids Dam (Gilmore et al. 1990). Statistical analysis of groundwater and river stage data for the period from October 1989 through February 1990 indicate there is a strong correlation between river stage and the water table fluctuations in the 100-N Area in wells located 130 to 480 ft (39.6 to 146.3 m) from the Columbia River (Gilmore et al. 1990). However, wells located between 860 and 2,570 ft (262.1 to 783.3 m) from the river did not show significant correlations between water-level fluctuations and river stage elevation during this period. A review of the data presented in Gilmore et al. (1990) for the 100-N Area indicates that high river elevations cause a reversal in the groundwater gradient near the river. The hydraulic gradient

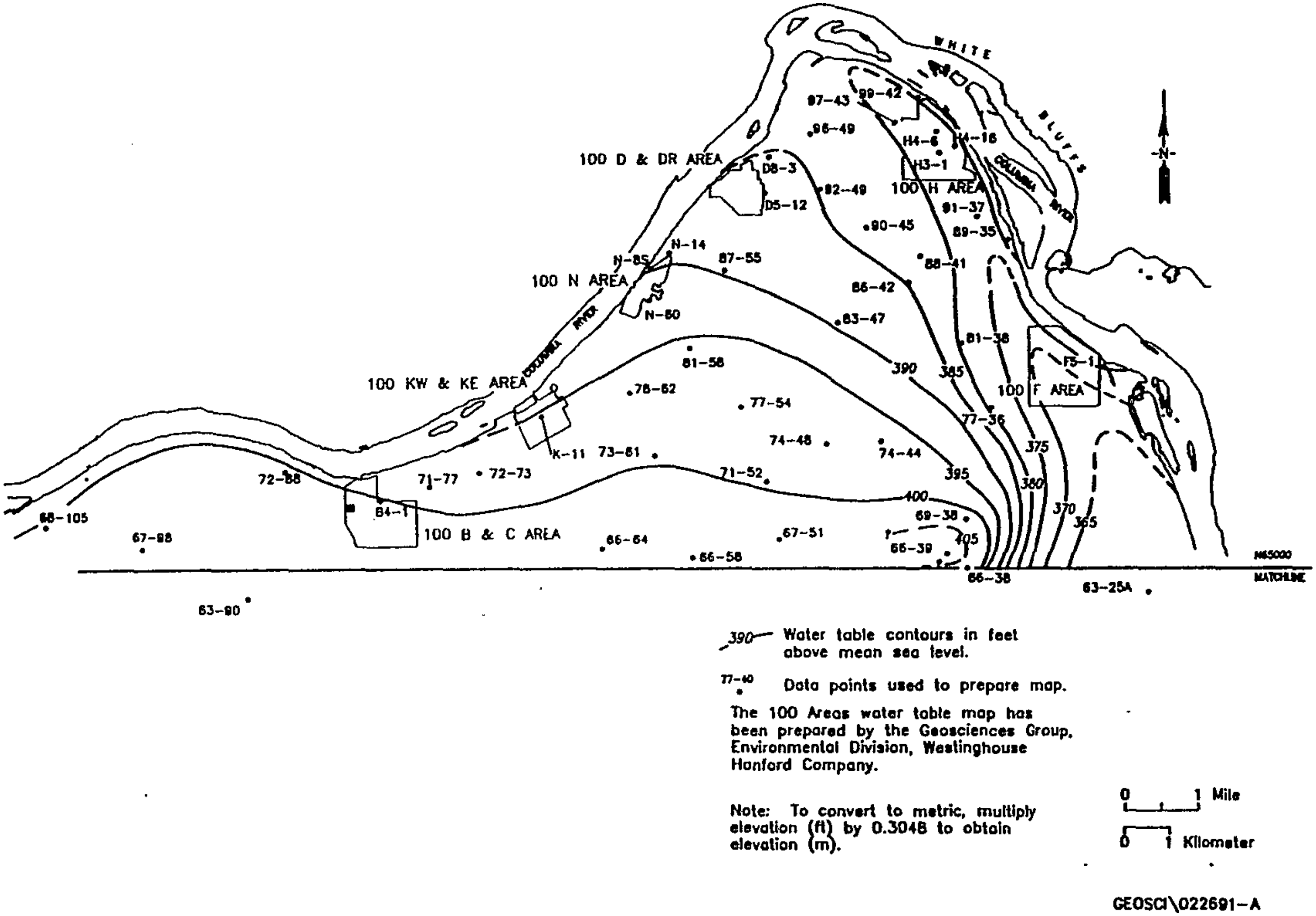

Figure 3-6. 100 Areas Water Table Map, June 1990 (Kasza et al. 1990).

reversal also has been documented in the 100 H area (Peterson 1990). In the 100 N area, the time lag between changes in the river stage and the corresponding effects in the wells located within 480 ft (146.3 m) of the river was found to range from less than 1 h up to 15 h. The cause of the absence of a correlation between river stage elevation and water-level in wells more distant from the river is not known. However, it is important to note that the study reported by Gilmore et al. (1990) was not conducted during time of peak river state and probably does not reflect the maximum impact that the river may have on the groundwater gradient. Those changes in water level elevation observed in wells farthest from the river may have resulted from a pressure response. Changes in stage of the Columbia River may have increasing impact on groundwater flow at the 100 Areas because as mounds dissipate, the changes in stage will have an increasing influence.

3.2.2 200 Area Hydrogeology

The 200 Areas contain inactive nuclear fuels reprocessing and plutonium separations facilities, as well as the majority of radioactive waste storage and disposal facilities on the Hanford Site. More than 45 years of operations in these areas have resulted in the storage, disposal, and accidental release of radioactive and hazardous wastes.

The hydrostratigraphic units of concern in the 200 Areas are (1) the Rattlesnake Ridge interbed, (2) the Elephant Mountain Basalt Member, (3) the Ringold Formation, (4) the Plio-Pleistocene unit and early "Palouse" soil, and (5) the Hanford formation (Figure 3-7). The Plio-Pleistocene unit and early "Palouse" soil are only encountered in the 200 West Area. Rocks below the Rattlesnake Ridge interbed are not discussed because the more significant water-bearing intervals, relating to environmental issues, are primarily closer to ground surface. The hydrogeologic designations for the 200 Areas were determined by examination of borehole logs and integration of these data with stratigraphic correlations from existing reports.

The uppermost regionally extensive aquifer beneath the 200 Areas consists of the Rattlesnake Ridge interbed, the overlying flow bottom of the Elephant Mountain Member, and the underlying flow top of the Pomona Member. The Rattlesnake Ridge interbed consists of a clayey basalt conglomerate, an epiblastic fluvial-floodplain unit, an air-fall tuff, and a tuffite derived from fluvial reworking of the tuff and detrital sediments (Graham et al. 1984). The interbed is 50 to 82 ft (15.2 to 25 m) thick beneath the 200 Areas and generally thickens toward the west (Graham et al. 1981, 1984). Recharge to the Rattlesnake Ridge interbed aquifer occurs in the higher elevations surrounding the Pasco Basin to the west, north, and northeast. The flow of groundwater is generally toward the northeast beneath the 200 West Area and west to west-northwest beneath the 200 East Area. Graham et al. (1981, 1984) reported transmissivity values of 8 to 1,165 ft^2/d (2.4 to 355.1 m^2/d) over the entire thickness of the aquifer.

Beneath the 200 Areas the Rattlesnake Ridge interbed aquifer is generally separated from the overlying uppermost aquifer system by the Elephant Mountain Member. The Elephant Mountain Member is up to 115 ft (35 m) thick and divided into two flow units separated by an interflow zone approximately 3 ft (.9 m)

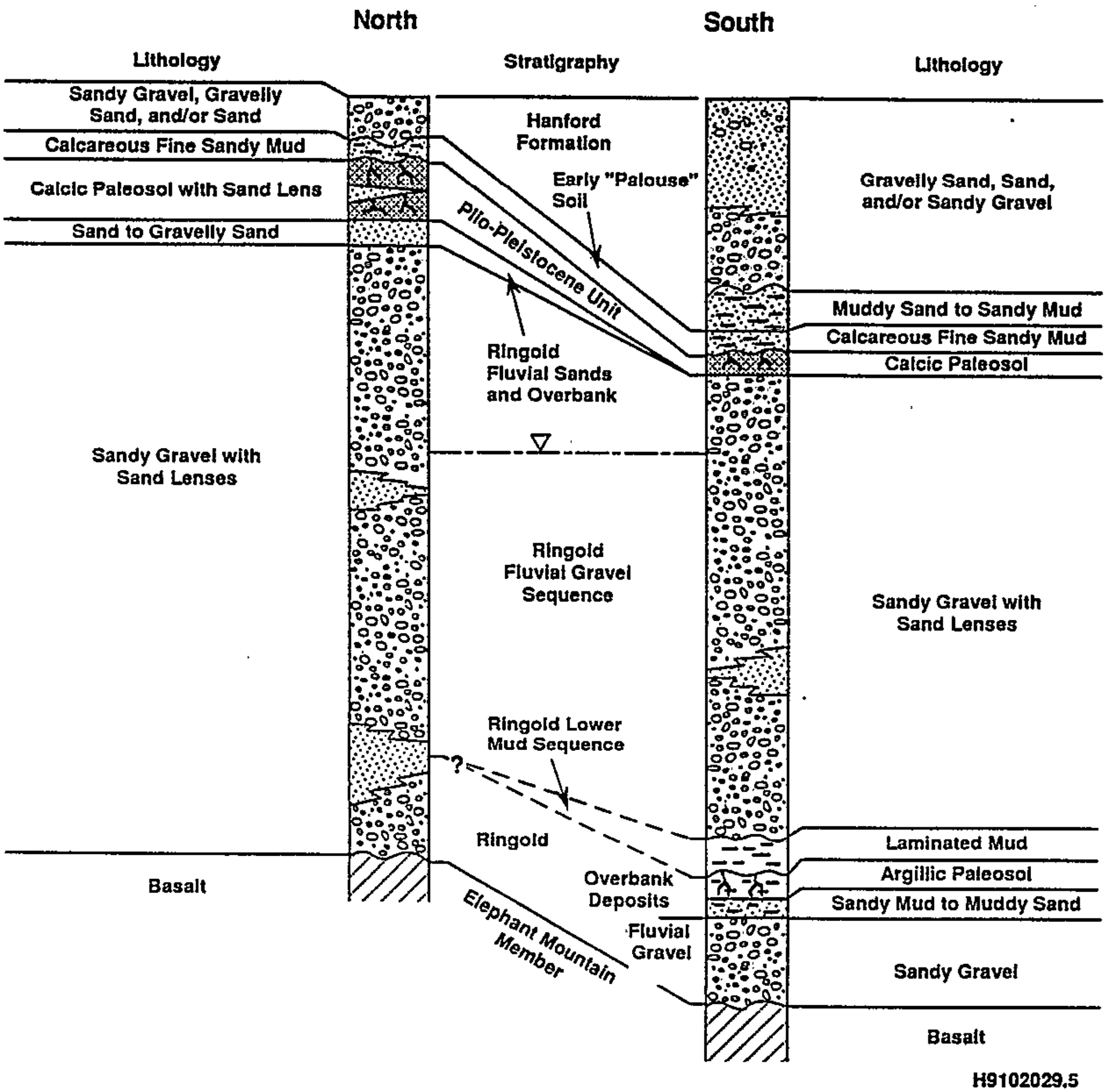

Figure 3-7. Conceptual Geologic and Hydrogeologic Column for the 200 Areas (Last et al. 1989).

thick that consists of interconnected vesicles and rubble zones (Graham et al. 1984; Gephart et al. 1979). This interflow zone is found south and west of the 200 East Area and in the vicinity of B Pond. In the northeast section of the 200 East Area the upper flow and the interflow zone have been removed by erosion (Graham et al. 1984). The Elephant Mountain interflow zone exhibits higher transmissivity values (7.5 to 6,120 ft^2/d; 0.7 to 569 m^2/d) than the bounding flows (Graham et al. 1984).

North of the 200 East Area the Elephant Mountain Member has been locally removed by erosion, allowing hydraulic communication between the underlying Rattlesnake Ridge interbed aquifer and the overlying uppermost aquifer system. Graham et al. (1984) determined that contamination found in the Rattlesnake Ridge interbed aquifer resulted from intercommunication through erosional windows between it and the overlying unconfined aquifer. According to Graham et al. (1984), a reversal in hydraulic gradient from an upward to a downward gradient may occur near erosional windows, resulting from artificial recharge mounding (i.e., Gable Mountain Pond), and where boreholes penetrate the Rattlesnake Ridge interbed (i.e., Well E33-12). In addition, intercommunication between the unconfined and Rattlesnake Ridge interbed aquifers may occur along cooling joints and fractures in the Elephant Mountain Basalt Member.

Where the Rattlesnake Ridge interbed aquifer is hydraulically connected with the unconfined aquifer via erosional windows, the Rattlesnake Ridge interbed is no longer confined. Consequently, where erosional windows occur the uppermost confined aquifer is the Selah interbed. The Selah interbed is a variable lithologic mixture of tuff, clay, sand, and gravel lying between the Pamona and Esquatzel Members of the Saddle Mountain Basalt. The Selah interbed is present primarily in the Cold Creek syncline. The interbed is 15 to 22 ft (4.6 to 6.7 m) thick beneath the 200 East Area and 45 to 70 ft (13.7 to 21.3 m) thick under the 200 West Area. Transmissivity values for the Selah interbed range from 3 x 10^{-3} ft^2/d (3 x 10-4 m^2/d). In the Gable Gap area north of the 200 Areas, several basalt flows have been removed by erosion, allowing direct hydraulic communication between the highly conductive sediments of the uppermost aquifer system and sedimentary interbeds below the Selah interbed.

The uppermost aquifer system in the 200 Areas occurs primarily within the sediments of the Ringold Formation and Hanford formation. In the 200 West Area the upper aquifer is contained within the Ringold Formation and displays unconfined to locally confined or semiconfined conditions. In the 200 East Area the upper aquifer occurs in the Ringold Formation and Hanford formation. The depth to groundwater in the upper aquifer underlying the 200 Areas ranges from approximately 190 ft (57.9 m) beneath the former U Pond in 200 West Area to approximately 340 ft (103.6 m) west of the 200 East Area. The saturated thickness of the unconfined aquifer ranges from approximately 220 to 368 ft (67.2 to 112.2 m) in the 200 West Area and approximately 200 ft (61 m) in the southern 200 East Area to near 0 ft in the northeastern 200 East Area where the aquifer thins outs and terminates against the basalt located above the water table.

Ringold sediments in the uppermost aquifer system in the 200 East Area are dominated by fluvial gravels of unit FSE that overlie the basalt of the Elephant Mountain Member. Significant silt- and clay-dominated intervals are absent except in the southwest part of the 200 East Area and east of B Pond where the lower mud sequence is found. Sandy gravels dominate the Hanford formation in the uppermost aquifer system in the 200 East Area.

The uppermost aquifer system in the 200 West Area occurs primarily within the Ringold Formation. The lower part of the upper aquifer system consists of unit FSA and generally is confined by fine-grained sediments of the lower mud sequence. The thickness of this confined zone ranges from greater than 50 ft (15.2 m) in the southern portion of the 200 West Area to less than 20 ft (6.1 m) beneath the northern portion of 200 West Area (Last 1989). The lower mud sequence is absent in the northern portion of 200 West Area, and a single, undifferentiated gravel sequence consisting of unit FSA and the overlying deposits of unit FSE is found. In this area it is not possible to hydraulically differentiate units FSA from FSE. The confining zone overlying unit FSA is up to 70 ft (21.3 m) thick below the western section of 200 West Area before pinching out in the eastern section of the 200 West Area. A mean hydraulic conductivity of 5.19×10^{-5} ft/d (1.6×10^{-5} m/d) has been obtained for these fines from permeameter testing of core samples from the top of the unit (Last et al. 1989). The upper part of the uppermost aquifer system in the 200 West Area is contained mostly within the fluvial gravel of unit FSE. Unit FSE is more than 250 ft (76.2 m) thick in this area. Hydraulic conductivities range from 0.06 to 200 ft/d (0.2 to 61 m/d) (Last et al. 1989).

The vadose zone beneath the 200 Areas ranges from approximately 180 ft (54.9 m) beneath the former U Pond to approximately 340 ft (103.6 m) west of the 200 East Area (Last et al. 1989). Sediments in the vadose zone consist of the (1) fluvial gravel of Ringold unit FSE, (2) the upper unit of the Ringold Formation, (3) Plio-Pleistocene unit, (4) early "Palouse" soil, and (5) Hanford formation. Only the Hanford formation is continuous throughout the vadose zone in the 200 Areas. The upper unit of the Ringold Formation, the Plio-Pleistocene unit, and the early "Palouse" soil only occur in 200 West Area.

As much as 140 ft (42.7 m) of Ringold strata belonging to unit FSE occurs above the water table in the 200 West Area. However, in the northern half of the 200 East Area post-Ringold erosion has removed unit FSE as well as the entire Ringold Formation. Where this occurs, as well as where groundwater mounds derived from sustained discharge of waste water are found, the vadose zone occurs entirely within the Hanford formation.

Pre-Hanford strata that overlie Ringold unit FSE in the vadose zone are only found in the 200 West Area. These strata include: (1) fluvial sand and mud of the upper unit of the Ringold Formation, (2) calcretes and alluvium of the Plio-Pleistocene unit, and (3) loess of the early "Palouse" soil. The upper unit of the Ringold Formation reaches a maximum thickness of 35 ft (10.7 m) and is most commonly encountered in the central, northern, and western parts of the 200 West Area. Calcretes of the Plio-Pleistocene unit are up to 35 ft (10.7 m) thick and overlie the Ringold Formation throughout most of the 200 West Area. The top of the Plio-Pleistocene unit dips approximately 1.5 degrees to the southwest beneath the 200 West Area. The high cementation and laterally continuous nature of this unit may create an interval with relatively low permeability. Thus a potential exists for lateral movement of vadose zone recharge water above the Plio-Pleistocene unit. However, no perched water was reported by Last et al. (1989) above this unit, and, because of the arid conditions at the Hanford Site, the vadose zone flux is not expected to be sufficient to cause lateral movement of water along the Plio-Pleistocene unit. Unconsolidated loess or sandy silt up to 15 ft (4.6 m) thick and designated the early "Palouse" soil overlies the Plio-Pleistocene unit beneath the southern portion of 200 West Area. This deposit is uniformly fine grained, micaceous, and moderately calcium carbonate rich.

The Hanford formation is the uppermost unit in the unsaturated zone except for discontinuous recent eolian sands present in the northwestern section of the 200 West Area. Hanford sediments range from fine-grained silty sands in the southern parts of the 200 Areas to granule to boulder gravels in the northern part of the 200 Areas. The Hanford formation is less than 20 ft (6.1 m) thick where the Plio-Pleistocene unit is near the surface (Last et al. 1989) to more than 140 ft (42.7 m) thick. Last et al. (1989) suggested that a flood channel exists in the southern portion of 200 West Area. The thickness of deposits in this area ranges from approximately 80 ft (24.4 m) to nearly 150 ft (45.7 m). On the average, field moisture content of unsaturated Hanford formation sediments beneath the 200 Area ranges from 2% to slightly greater than 6% (Last et al. 1989).

Artificial recharge to the unconfined aquifer is estimated to be ten times greater than natural recharge (Graham et al. 1981). The major sources of artificial recharge in the 200 Areas have been three waste ponds designated U Pond, Gable Mountain Pond and B Pond (Figure 3-2). A comparison of the hindcast water table map of the Hanford Site for 1944 (Figure 3-3) and the 200 Areas water table maps for June 1989 (Figure 3-4) indicates that the natural water table elevation in the 200 West Area was approximately 65 ft (19.8 m) lower in 1944. The hindcast map indicates that the direction of regional flow was toward the east, and the natural hydraulic gradient was on the order of 1 ft/1,000 ft in the 200 West Area. The U pond, located in the 200 West Area, and Gable Mountain Pond, located north of the 200 East Area, were decommissioned in 1984 and 1987, respectively. The B Pond is scheduled for decommissioning in the mid-1990's, but additional lobes associated with this pond are scheduled for continued effluent discharge.

Groundwater elevations for June 1990 for the unconfined aquifer in the 200 Areas are shown in Figure 3-8. Groundwater flow beneath the 200 West Area is generally toward the north and the east, away from the mound created by past discharges to U Pond. The horizontal hydraulic gradient is expected to decrease and shift to the east as the mound dissipates. The horizontal hydraulic gradient in the 200 West Area is relatively high, ranging from 4 ft/1,000 ft to 1.5 ft/1,000 ft (Graham et al. 1981). The steep gradient results from the presence of the water table exclusively in the Ringold Formation. Downward vertical hydraulic gradients are expected to be present within the unconfined aquifer in parts of the 200 West Area as a result of the U Pond groundwater mound (Graham et al. 1981).

Groundwater flow beneath the 200 East Area is complex because of the convergence of flow from the west (local groundwater flow system) and east (B Pond artificial recharge). This convergence of flow has caused groundwater within the unconfined aquifer to diverge from historical flow paths with a

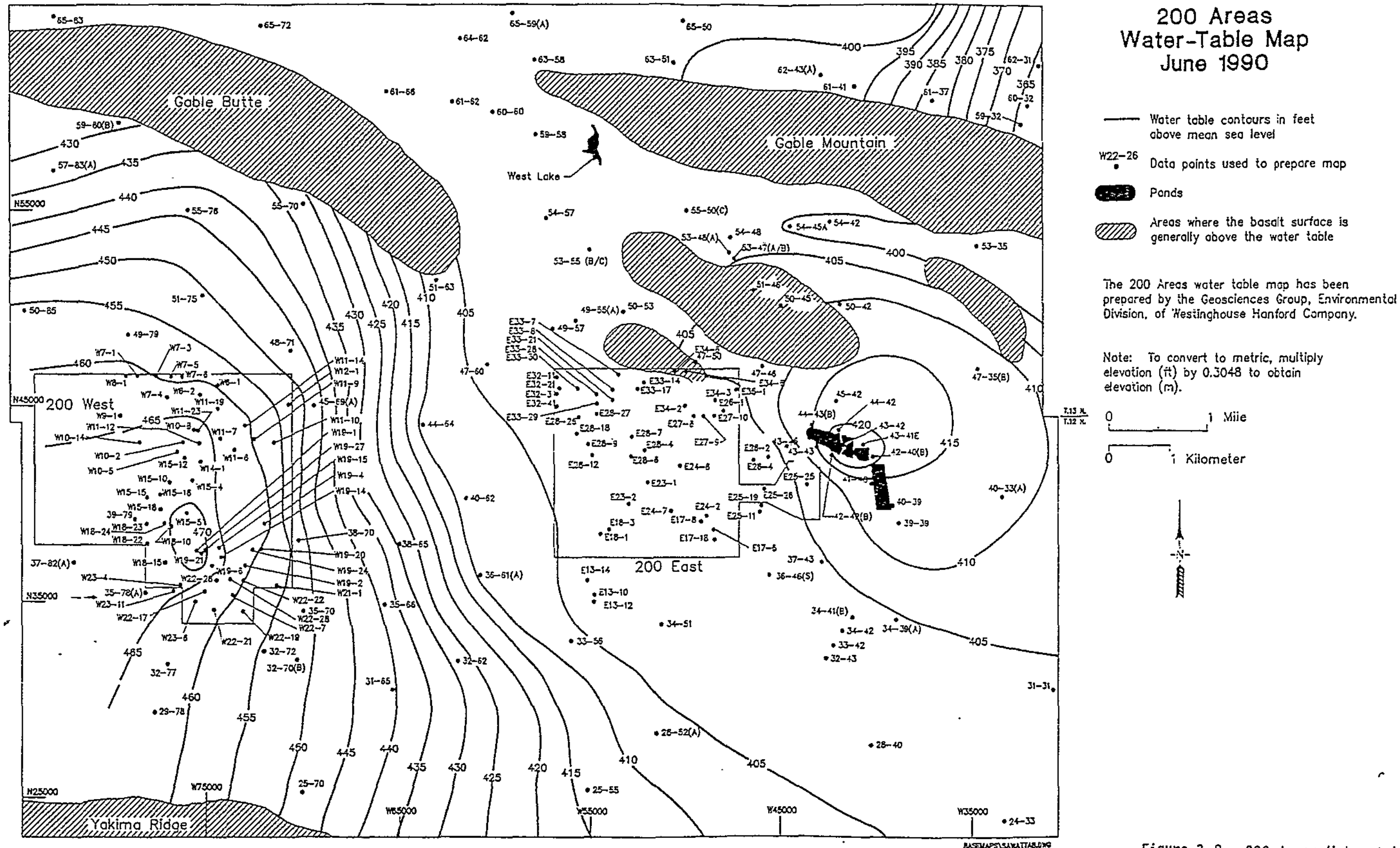

Figure 3-8. 200 Areas Water-table Map, June 1990 (Kasza et al. 1990).

component flowing northward between Gable Butte and Gable Mountain and another component flowing southeast toward the Columbia River (Figure 3-8). In addition, the high transmissivity beneath most of the 200 East Area (resulting from the presence of the water table in the Hanford formation) results in very small hydraulic gradients. Groundwater flow directions may change temporarily because of changing rates of wastewater discharged to B Pond and other disposal sites. Therefore, it is often difficult to define groundwater flow directions from water table maps of the 200 East Area. However, contaminant plume maps of the 200 Areas can indicate long-term trends in groundwater flow directions (Serkowski and Jordan 1989). These plume maps indicate a north-northwest direction of flow in the extreme north central portion of the 200 East Area and a south to southeast direction of flow in the southeast portion of the 200 East Area.

3.2.3 1100 Area

The 1100 Area, which is adjacent to the city of Richland in Benton County, composes the southeastern-most portion of the Hanford Site (Figure 3-9). The 1100 Area has been used as a maintenance area, warehouse facility and equipment storage yard in support of operations at the Hanford Site. Until recently, the 1100 Area was not included within the Hanford groundwater monitoring network, so detailed hydrogeologic data are limited to the 1100-EM-1 Operable Unit. The hydrogeologic system underlying the 1100 Area and vicinity is similar to the regional hydrogeologic model of the Hanford Site. Hydrostratigraphic units in the 1100 Area consist of the (1) Ice Harbor Member of the Saddle Mountains Basalt, (2) lower confined zones in the Ringold Formation, and (3) upper unconfined zones in the Ringold Formation and Hanford formation. Deeper zones are not discussed because the more significant water-bearing intervals are closer to ground surface.

The Ice Harbor Flow of the Saddle Mountains Basalt is the uppermost basalt below the 1100 Area (DOE 1988). The basalt is situated at approximately 190 ft (57.9 m) below ground surface. Immediately overlying the basalt, a silt layer is present with an estimated hydraulic conductivity on the order of 10^{-3} ft/d (3×10^{-4} m/d) (DOE 1988).

The uppermost aquifer system occurs within both the Hanford and Ringold formations. The upper aquifer is divided into a semiconfined lower part and an unconfined upper part by a discontinuous silt aquitard (Figure 3-8). The silt aquitard consists of overbank deposits of the Ringold Formation. One or more confined to semiconfined zones likely occur below this aquitard. Of these zones data are only available for the upper one. The upper confined zone consists of fluvial gravels and sands of Ringold units FSC and FSB; it is a few feet to over 30 ft (9.1 m) thick, and its horizontal and vertical extent is not presently well defined. Lindberg and Bond (1979) show the upper confined zone merging with the overlying unconfined aquifer near the Columbia River within the 300 Area. Hydraulic conductivity values for the confined aquifer range from 3×10^{-1} to 5 ft/d (1×10^{-1} to 1.5 m/d) (Lindberg and Bond 1979). Groundwater measurements indicate that flow is easterly, with an upward vertical gradient.

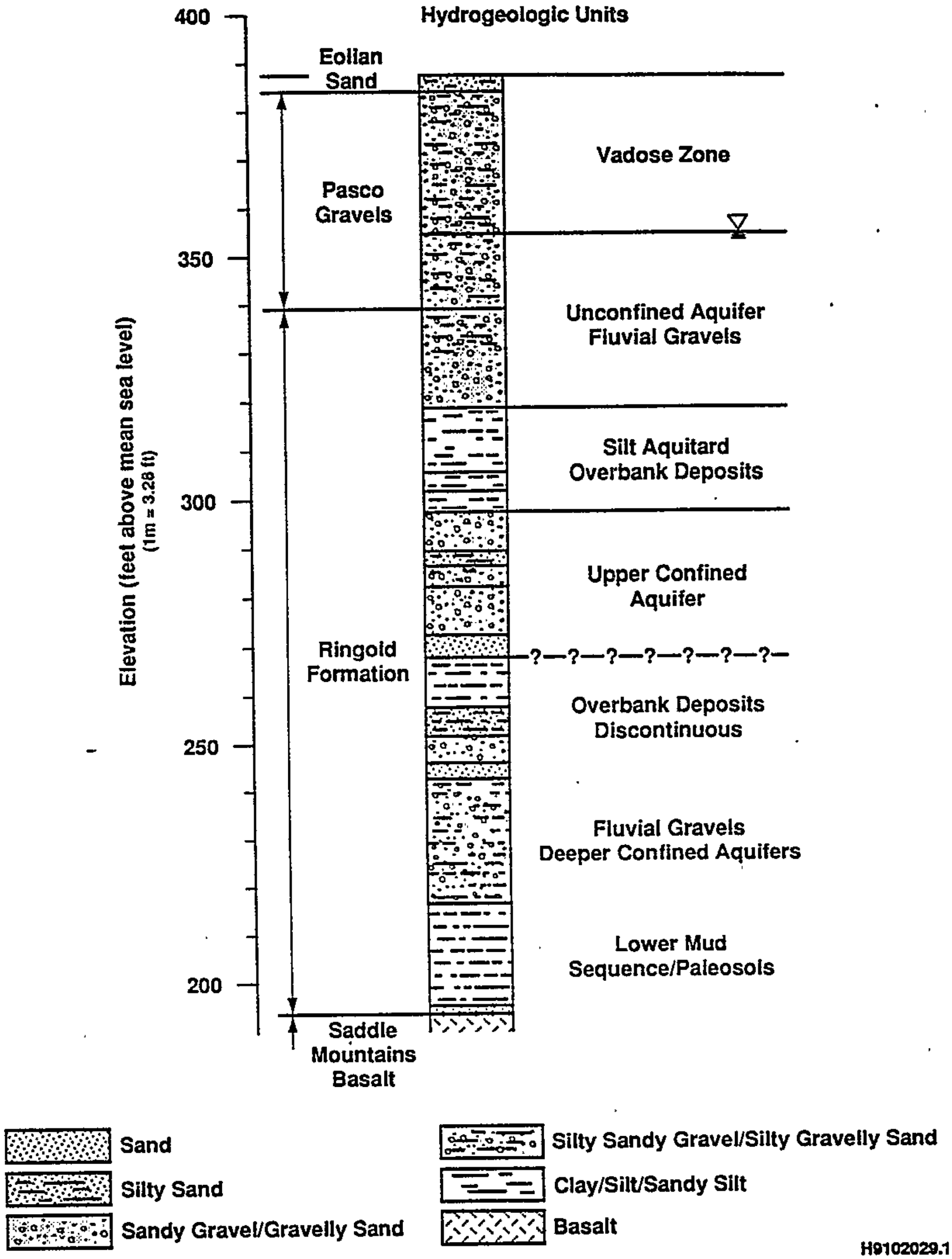

Figure 3-9. Conceptual Geologic and Hydrogeologic Column for the 1100 Area (DOE/RL 1990a).

The silt aquitard is common throughout the 1100 Area (Newcomb et al. 1972; Lindberg and Bond 1979; Bryce and Goodwin 1989) although it is unclear how laterally extensive it is outside the area. The silt aquitard is 4 to 33 ft (1.2 to 10.1 m) thick, and the top commonly is eroded. The vertical hydraulic conductivity in the aquitard ranges from 8×10^{-4} to 1×10^{-1} ft/d (2×10^{-4} to 3×10^{-2} m/d). In general, an easterly decline in the hydraulic gradient across the aquitard is anticipated because the aquitard likely pinches out in this direction, thereby allowing the unconfined aquifer to equilibrate with the groundwater zone below (Lindberg and Bond 1979).

The unconfined aquifer below the 1100 Area occurs predominantly within fluvial gravels of the Ringold Formation and coarse-grained deposits of the Hanford formation. The continuity of this aquifer with the unconfined aquifer occurring elsewhere below the Hanford Site and east of the 1100 Area is shown by the general similarity of geologic strata and groundwater potential between these locations. The aquifer is 16 to 44 ft (4.9 to 13.4 m) thick below the 1100 Area and thickens towards the Columbia River. The hydraulic conductivity in the unconfined aquifer is 2 ft/d (0.6 m/d) in the 1100 Area. In general, this hydraulic conductivity is slightly lower than values typically measured in the unconfined aquifer elsewhere. For wells screened entirely within Ringold fluvial gravels, a geometric mean of 3 ft/d (0.9 m/d) is obtained. For wells screened entirely within the Hanford Formation, the geometric mean hydraulic conductivity is 10 ft/d (3.4 m/d).

The unsaturated (vadose) zone consists predominantly of interbedded sandy gravel, gravelly sand, and silty sandy gravel of the Hanford formation. The depth to the water table varies from 20 ft (6.1 m), west of Horn Rapids Landfill, to 50 ft (15.2 m) at the south end of the 1100 Area. Hydraulic testing to evaluate vadose zone recharge to groundwater was not conducted in the 1100 Area. Rockhold et al. (1990) collected drainage and moisture data for the vadose zone at several locations. Two of these locations are within 10 mi (3.1 km) of the 1100 Area, and based on Rockhold's results, recharge through the vadose zone at the 1100 Area is anticipated to vary from 0 to 4.5 in/yr (11.4 cm/yr). The upper end of this range is anticipated within disturbed sites because of the lack of vegetation and the occurrence of generally coarse-grained sediments. Away from the disturbed areas, where the ground surface is generally vegetated with grasses and shrubs and the sediments are finer grained, the lower end of the range is more probable.

Groundwater recharge to the unconfined aquifer below the 1100 Area and vicinity results from westward groundwater inflow from the Yakima River. The Yakima River discharges directly to the unconfined aquifer along the Horn Rapids reach below Horn Rapids Dam (Freshley et al. 1989). Irrigation losses in the area west of the 1100 Area likely contribute to the westward groundwater inflow volume.

East of the 1100 Area, the city of Richland well field artificially recharges the unconfined aquifer. This major source of recharge to the aquifer causes groundwater mounding, which extends west of the well field. However, because the well field is recharged intermittently, the mound may dissipate between periods of recharge. Monthly totals for recharge at the well field during 1988 and 1989 ranged from about 2×10^7 gal to 4×10^8 gal.

Groundwater elevations for May 1990 for the unconfined aquifer in the 1100 Area and vicinity are shown in Figure 3-10. This map shows northeasterly groundwater flow in the vicinity of Horn Rapids Landfill, easterly flow near the city of Richland well field, and easterly-to-southeasterly flow south of the well field. During periods of artificial recharge at the Richland well field, a groundwater mound is created below the recharge ponds. The groundwater mound is visible on the May 1990 water-level contour map. On March 5, 1990, the mound had a height of approximately 1.5 ft (0.5 m) before recharge and a radius of about 500 ft (152.4 m).

Groundwater discharge from the unconfined aquifer is primarily into the Columbia River and to wells in the city of Richland well field. Hydraulic connection between the aquifer and the river is shown by the continuity of the formation materials toward the river and the similarity between river state and the observed groundwater potential in the unconfined aquifer near the river (DOE/RL 1990). This hydraulic connection was further demonstrated by the response of a number of monitoring wells to a 1 ft (0.3 m) decline in Columbia River stage from March 2 to March 5, 1990. During this period, groundwater potential measured in monitoring wells nearest the river also declined approximately 1 ft (0.3 m).

3.2.4 300 Area

The 300 Area, located in the southeastern portion of the Hanford Site, contains a number of support facilities for the Hanford Site, including a convertible oil and coal powerhouse for process steam production, a Columbia River raw water intake, treatment, and storage facility; and other facilities necessary to support fuels production, research and development. Unconfined and confined aquifers are present beneath the 300 Area. The uppermost aquifer is unconfined; the first underlying confined aquifer is contained in the flow top of the uppermost basalt and, locally in some areas of the 300 Area, the lowermost portion (less than 5 ft [1.5 m]) of the Ringold Formation.

The hydrostratigraphic units in the 300 Area are, in ascending order, as follows: (1) Levey interbed and Ice Harbor Member of the Saddle Mountains Basalt, (2) the lower mud sequence and fluvial gravels of Ringold units FSE, FSC, and FSB, (3) coarse-grained deposits of the Hanford formation, and (4) eolian sand (Figure 3-11).

The Levey interbed is the uppermost confined aquifer in the 300 Area. This aquifer consists of the flow bottom of the Ice Harbor Basalt, the flow top of the Elephant Mountain Basalt, and the Levey interbed. Hydraulic conductivities for the Levey interbed range from 0.01 to 1,000 ft/d (0.003 to 304.8 m/d). The overlying Ice Harbor Member acts as a confining unit to the Levey interbed aquifer, separating it from the overlying upper or suprabasalt aquifer (DOE/RL 1990).

The uppermost aquifer system in the 300 Area, as throughout most of the Site, is located in the Ringold Formation and Hanford formation. The lower mud sequence of the Ringold Formation forms the base of the upper aquifer and acts as a local confining unit to discontinuous sand lenses located on top of the Ice Harbor Member. The lower mud sequence is up to 60 ft (18.3 m) thick in the 300 Area except in the north where it pinches out.

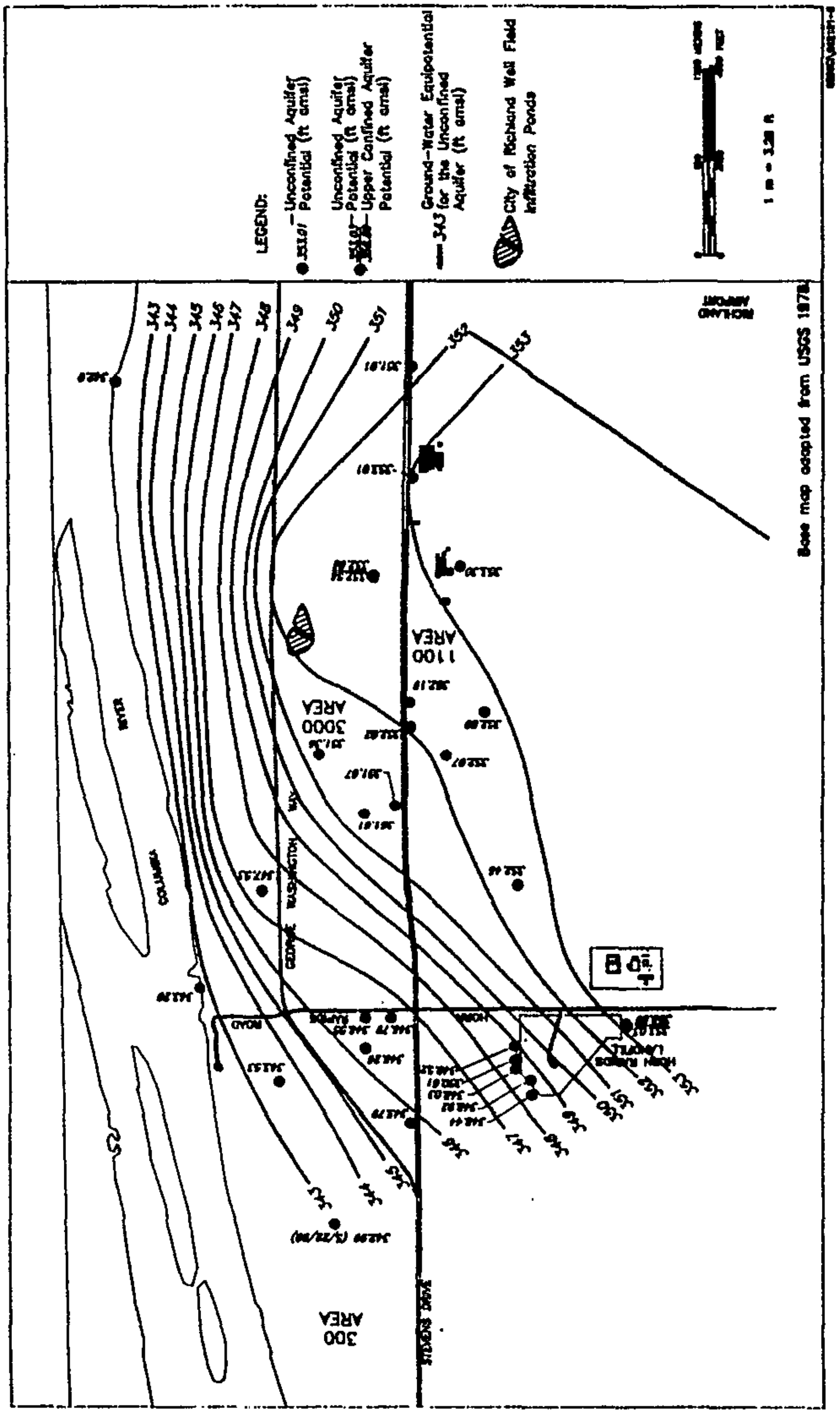

Figure 3-10. 1100 Area Water Table Map, May 1990
(from Kasza et al. 1990).

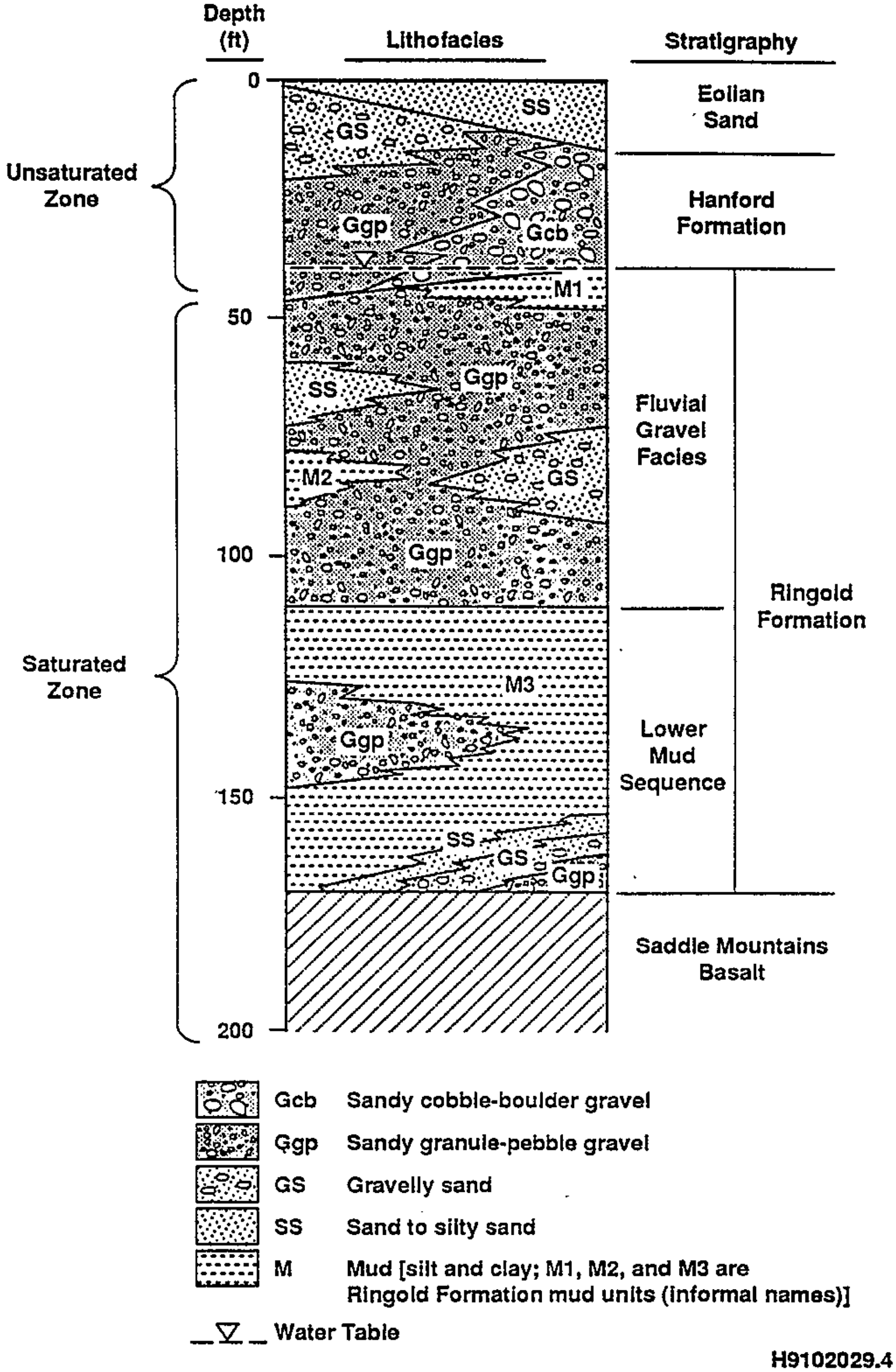

Figure 3-11. Geologic and Hydrogeologic Column for the 300 Area (DOE/RL 1990).

The main body of the upper aquifer occurs in the fluvial gravels of Ringold units FSE and possibly FSC and FSB. These gravelly deposits reach a maximum thickness of approximately 70 ft (21.3 m) in the 300 Area and are inferred to be laterally continuous in the area. The lower part of the unconfined aquifer in the fluvial gravel facies may be hydraulically isolated by discontinuous thin interbeds of silt and clay. The hydraulic properties of the unconfined aquifer vary considerably with location, the result of changes in local stratigraphy. Hydraulic conductivities measured in the 300 Area for the Ringold Formation vary from 1.9 to 10,000 ft/d (0.6 to 3,048 m/d). The hydraulic conductivity of the unconfined aquifer generally decreases with depth (DOE/RL 1990).

In the 300 Area, the water table is located near the contact between the Hanford formation and Ringold Formation. The water table is at a depth of approximately 30 to 70 ft (9.1 to 21.3 m) below the land surface, and the top of the Ringold Formation is at a depth of 35 to 65 ft (10.7 to 19.8 m) below land surface. Therefore, depending on location, the water table is present in both formations.

The Hanford formation in the 300 Area typically consists of sandy gravel with cobbles and boulders increasing with depth. The Hanford formation varies from 30 to 65 ft (9.1 to 19.8 m) in thickness, but only a small part (up to 15 ft [4.6 m]) of the lower half of the unit is usually saturated with water. Hydraulic conductivities measured in the 300 Area for the Hanford formation vary from 11,000 to 50,000 ft/d (3,353 to 15,240 m/d).

The vadose zone in the 300 Area generally is about 40 to 50 ft (12.2 to 15.2 m) thick and lies almost entirely within the gravels of the Hanford formation. The 300 Area lysimeter data indicate that water is moving downward below the root zone. Estimates of recharge rates are 1 to 3 in./yr (2.5 to 7.6 cm/yr) for grass-covered soils (Kirkham and Gee 1984). In contrast, no drainage occurred at a lysimeter at the same location with deep-rooted vegetation (Gee et al. 1989). Coarse-grained soils, shallow-rooted plants, and above-normal precipitation during the measurement period have enhanced recharge estimates at this location (Gee and Heller 1985).

Groundwater flow across the 300 Area is generally to the southeast. However, in the southern part of the 300 Area there is a component of groundwater flow from the Yakima River southwest of the 300 Area. As a result, groundwater enters the 300 Area from the northwest, west and southwest (Lindberg and Bond 1979). A water-level contour map of the 300 Area for May 1987 is shown in Figure 3-12. Groundwater flow in the 300 Area also is influenced by water level in the Columbia River. Lindberg and Bond (1979) show that when the river stage rises bank storage increases and the water table gradient is temporally reversed. During these periods, groundwater tends to flow in a more southerly direction, roughly subparallel to the river. When the river level drops, the general gradient is restored and groundwater flows more easterly in a direction nearly perpendicular to the river. The effects of river-level fluctuation have been measured at locations up to 2.5 mi (4.0 km) from the river. Lindberg and Bond (1979) suggest that a paleoriver channel exposed in a 1958 excavation is responsible for the rapid response of groundwater levels to changes in river stage.

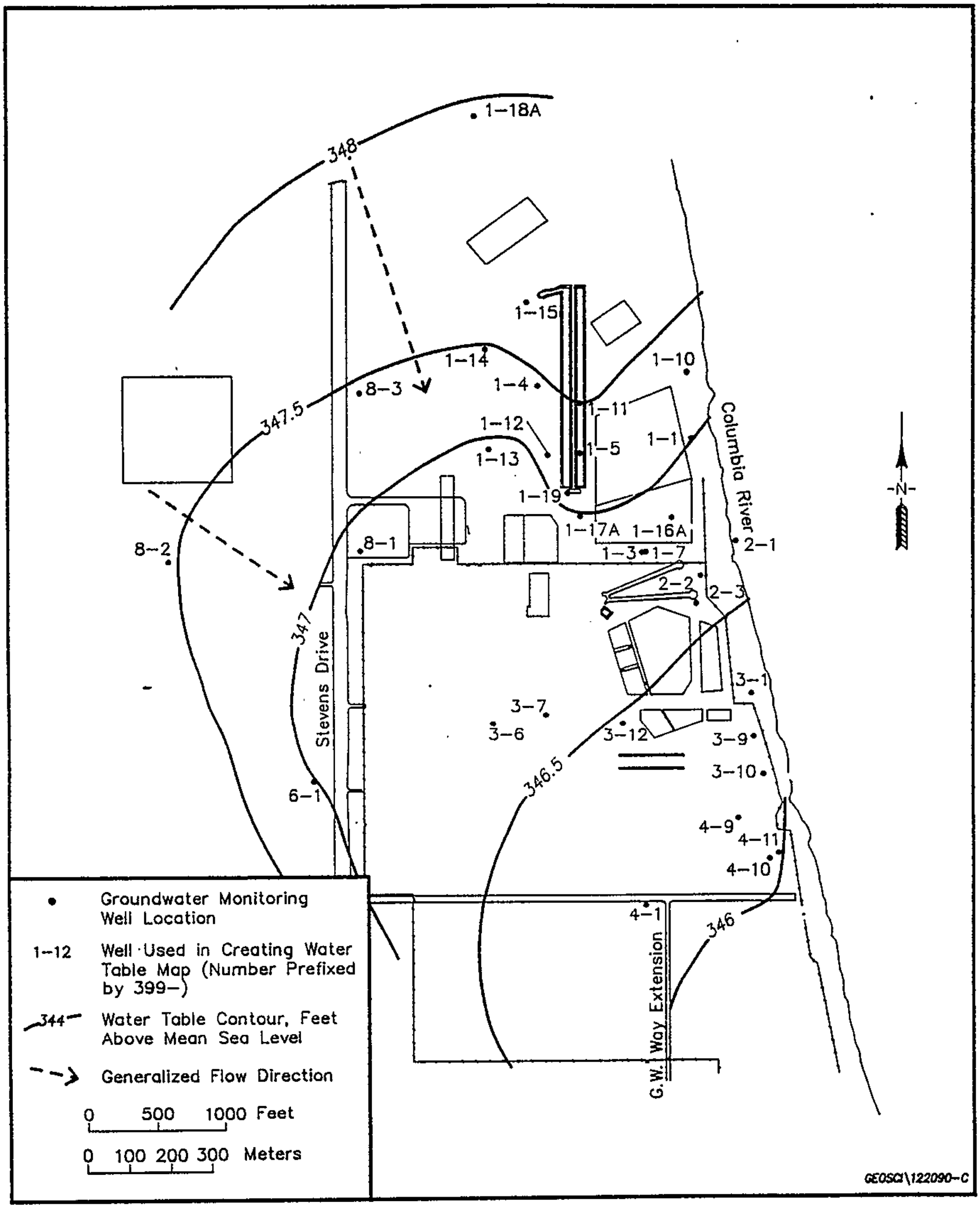

Figure 3-12. 300 Area Water Table Map, May 1987 (Schalla et al. 1988).

The primary man-made influence on groundwater level and flow direction in the 300 Area is from process trenches. Discharge to the trenches is up to 3,000,000 gal/d (11,356,200 L/d). Discharge to the nearby sanitary trenches range up to 500,000 gal/d (1,892,700 L/d). These large volumes of water percolate quickly to the groundwater and create small groundwater mounds. The mounds increase the water table gradient and produce divergent flow, particularly around the process trenches.

Two types of surface water exist on the 300-FF-5 operable unit: the Columbia River and groundwater seeps along the riverbank. Small springs found along the river in the 300 Areas flow intermittently, influenced primarily by changes in river level. The volume of the seep discharges has not been quantified. However, estimates of seepage from a stretch of the river upstream of the 300 Area were as low as 3 ft^3/s (0.9 m^3/s), as compared to the 100,000 ft^3/s (30,480 m^3/s) of the Columbia River (Cline et al. 1985). No other naturally occurring surface water exists on or near the 300 Area.

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